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EFFECT OF PERCENTAGE OF PROTEIN IN THE DIET ON GROWTH AND FEED UTILIZATION OF MALE CHICKENS[1]

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INTRODUCTION

The optimum percentage of protein in the diet of the growing chick is of practical importance and scientific interest. Hence, a great deal of scattered research on the protein requirements for growth of chickens has been done with birds of different ages and breeds, under different systems of management, and fed protein from various sources. Even in some of the most carefully planned earlier studies of the protein requirements of chickens for growth, the significance of the results is doubtful in the light of present knowledge of the vitamins. It is probable that in some cases a part of the difference attributed to the level of protein intake was due to difference in vitamin G or mineral intake.

The experiment described in this paper was carried out for the purpose of obtaining extensive and reliable data on (1) the effect of the level of protein intake on growth of male chickens, utilization of feed, utilization of protein, and the relationship between feed consumption and live weight; and (2) the influence of limited feeding on the relationship between growth response and the level of protein intake. The experiment provided for (1) the limited feeding of seven diets containing different percentages of protein to seven lots of male chickens and the ad libitum feeding of the same diets to another seven lots of males, for a period of 52 weeks; (2) collecting the pertinent data on feed consumption, live weight, and mortality; and (3) making a mathematical analysis of the data. The limited-fed birds received 70 percent of the normal feed intake. Male chickens were used in this experiment so that the influence of egg production on feed consumption and growth would be avoided.

REVIEW OF LITERATURE

Papers on the protein requirements of growing chicks and on closely allied subjects have been published by many workers. Mussehl and Gish (*10*)[2] found that the rate of growth of chicks during the first 9 weeks was improved as the level of crude protein in the diet was increased to approximately 19 percent. Meat scrap was the chief source of protein in their diets. Holst (*6*) suggested that chicks should be fed a diet high in protein when first given feed and that the percentage of protein should be decreased progressively as the chicks advanced in age.

[1] Received for publication November 9, 1937; issued June, 1938.
[2] Reference is made by number (italic) to Literature Cited, p. 810.

Norris and Heuser (*11*) reported that chicks made the best growth during the first 8 weeks on a diet containing 20 percent of protein. Diets containing more than 20 percent were not studied. They also found that as the age of their birds increased the efficiency of protein utilization decreased, and that as the protein content of a diet increased the efficiency of feed utilization increased but in birds of the same age the efficiency of protein utilization decreased. Heuser and Norris (*4*) concluded that the growth of chicks is divided into three periods of about 6 to 7 weeks each and that during these three periods the following percentages of protein are the smallest that will produce rapid growth: 20 percent during the first period, 18 percent during the second, and 15 to 16 percent during the third.

Swift, Black, Voris, and Funk (*15*) found that the greatest gain in weight was obtained with a protein content of 22.9 percent in the diet and that the smallest gain was obtained with a protein content of 14.7 percent. Morris (*9*) reported that lots of chicks fed diets containing 14.32 to 23.13 percent of protein all consumed about the same quantity of feed but that the lots fed the higher percentage of protein grew best. Milne (*8*) obtained excellent growth with chicks fed diets containing 22.5 and 30.5 percent of protein during the first 6 weeks. When the protein was fed at a level of approximately 38.8 percent, growth was adversely affected after the third week. However, when the initial level of protein intake was reduced by decrements of 4.5 percent from 38.8 to 16.3 percent during the first 6 weeks, the chicks made approximately the same gain as those having a level of protein intake of 30.5 percent throughout the period. St. John, Carver, Johnson, and Brazie (*13*) found that 21 percent of protein gave the best early growth but was closely followed by approximately 17 percent. They found also that after the chicks were 10 weeks old a diet containing 13 percent of protein gave a satisfactory growth and that regardless of the level of protein intake the birds tended to reach the same live weight at 24 weeks of age.

Tepper, Charles, and Reed (*16*) reared chicks in batteries and found that 20 percent of protein, which was the highest level they studied, was the most efficient up to 13 weeks of age. Diets having a protein content of less than 17 percent were not found to be desirable for brooding chicks in batteries. Efficiency of feed utilization, based on gains in weight, decreased with advancing age. Birds on low protein levels matured more slowly both physically and sexually than those on higher levels of protein. Heuser and Norris (*5*) concluded that with the possible exception of birds fed diets extremely low in protein all birds of the same breeding finally reach about the same live weight. The strain they used reached about the same weights at 29 to 30 weeks when the quantity of protein consumed was sufficient to support growth. They believed that "mortality is probably affected where the protein level is very low and thus growth very much retarded." They stated that "mortality is possibly also greater where the protein level is excessively high, in which case there might probably be a deficiency of some other factor."

Wilgus, Norris, and Heuser (*18*) showed that the growth-promoting properties of the protein concentrates were, in general, due to their vitamin G content as well as to the quality of their protein. Norris, Heuser, Ringrose, Wilgus, and Heiman (*12*) presented evidence to show

that the requirements of chicks for vitamin G are extremely large. Heiman (*2*) has shown that 10 percent of dried whey insures ample vitamin G for growth.

Titus, Jull, and Hendricks (*17*) recommended that in comparative feeding experiments all the groups be fed a level of feed intake equal to 70 percent of an approximation of the idealized ad libitum feed consumption. They found that at the 70-percent level the value of the Spillman ratio was nearly as large as it was at the ad libitum level.

Carver, St. John, Miller, and Bearse (*1*) found that chicks fed skim-milk powder or Alaska herring fish meal at a 16-percent level of protein intake made better growth at 6 and 12 weeks of age than lots fed the same supplements at a 13-percent level. The pullets that received diets containing 13 and 16 percent of protein and in which the protein supplements were Alaska herring fish meal, meat scrap, or dried skim milk, showed very little difference in live weight at 24 weeks of age. Throughout the experiment, the pullets fed at a 13-percent level used the protein more efficiently than those fed at a 16-percent level. These investigators concluded that the protein requirements of pullets steadily decreased until the beginning of egg production.

McConachie, Graham, and Branion (*7*) found that the optimum protein content for growth in chicks during the first 6 weeks on the usual type of diet was approximately 25 percent. They concluded that for the first 12-week period approximately 19 percent of protein was the optimum amount and that a level of protein over 25 percent was detrimental to growth. These investigators reported that both high and low levels of protein intake, particularly the former, tended to destroy the barring and to change the contour and texture of the feathers. They also found "crow heads" to be associated with low protein intake and concluded that slipped tendons were not due primarily to a high protein intake per se.

EXPERIMENTAL MATERIAL AND METHODS

Approximately 1,100 cross-bred chicks were hatched in a commercial hatchery May 25, 1933, for use in this experiment. Barred Plymouth Rock females had been mated with Rhode Island Red males to obtain the advantage of the sex-linked barring factor for separating the sexes at hatching time. The male chicks arrived at the Agricultural Research Center, Beltsville, Md., where this experiment was carried on, early in the forenoon of May 26. They were weighed and the weak and otherwise unsuitable ones discarded. The 518 male chicks which remained were distributed among 14 pens so that each pen contained 37.

The chicks were brooded under electrically heated brooders in a series of pens, 11½ by 4 feet in size, in a hot-water-heated brooder house. They received their first feed and water when they were 1 day old. After they were 4 days old, they were allowed access to direct sunlight in concrete yards, 12½ by 4 feet in size, adjoining their pens.

When the birds were 12 weeks old, it was necessary to reduce the number per lot to 28 to avoid overcrowding. At 20 weeks the number in each lot was further reduced to 20 birds. In each instance the reduction was made in a manner that would not change the mean live weight of the lot.

THE DIETS

The diets fed in this experiment were made up of combinations of the feed mixtures shown in table 1.

TABLE 1.—*Feed mixtures used in the experimental diets*

Ingredient	High-protein feed mixture [1]	Low-protein feed mixture [2]	Ingredient	High-protein feed mixture [1]	Low-protein feed mixture [2]
	Percent	*Percent*		*Percent*	*Percent*
Wheat gray shorts	25.0	25.0	Wheat-germ meal	2.5	2.5
Ground yellow corn	20.0	37.4	Ground gypsum	2.0	2.0
Granulated casein	15.0	0	Ground limestone	2.0	2.0
Dried whey	10.0	10.0	Common salt	.5	.6
Rolled oats	10.0	10.0	Monocalcium phosphate	0	.3
Alfalfa leaf meal	5.0	5.0	Dicalcium phosphate	0	.2
Wheat bran	5.0	5.0			
Desiccated meat meal	3.0	0	Total	100.0	100.0

[1] Average crude protein content, 26.54 percent.
[2] Average crude protein content, 12.87 percent.

The percentage of crude protein in each batch of the feed mixtures was determined before they were combined to form the diets. Then the two feed mixtures and 2 percent of cod-liver oil were combined to form the seven diets, the average chemical composition of which is given in table 2. The chemical composition of the diets differed significantly only in protein and nitrogen-free extract. All the vitamins and mineral elements known to be essential in the nutrition of the chicken were present in adequate quantities, and the quantities of each in the several diets were approximately equal.

TABLE 2.—*Average proximate chemical analyses of the experimental diets*

Diet No.	Crude protein (6.25 × total N)	Nitrogen-free extract	Fat (ether extract)	Crude fiber	Ash	Moisture	True protein (6.25 × albuminoid N)	Non-protein nitrogen compounds	Calcium (Ca)	Phosphorus (P)
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	25.00	49.92	5.48	3.26	6.64	9.70	23.17	1.37	1.36	0.61
2	23.00	51.73	5.53	3.29	6.67	9.78	21.26	1.31	1.37	.61
3	21.00	53.54	5.58	3.32	6.70	9.86	19.36	1.24	1.37	.60
4	19.00	55.36	5.62	3.35	6.73	9.94	17.45	1.16	1.37	.60
5	17.00	57.18	5.67	3.38	6.76	10.01	15.55	1.09	1.37	.60
6	15.00	58.99	5.72	3.41	6.79	10.09	13.64	1.02	1.37	.60
7	13.00	60.80	5.77	3.44	6.82	10.17	11.74	.95	1.37	.60

These diets were fed to 14 lots of male birds, 7 of which were fed ad libitum and 7 of which were fed at a limited level approximating 70 percent of the idealized normal level of feed intake. The daily feed allowance for the limited-fed lots was calculated from the data compiled by Titus, Jull, and Hendricks (*17*) for males of this same cross.

Records were kept of the live weights of the chicks at the end of each week, of the quantities of feed consumed per chick per week, and of the mortality in each pen. The great volume of data compiled makes their complete publication impractical, hence only representative data are presented. The ages of the birds for which the data are presented are those at which cockerels are ordinarily marketed.

EXPERIMENTAL DATA

MORTALITY

The data in table 3 show the mortality by periods for the several lots. During the first 8 weeks the mortality was greater among the limited-fed birds than among those consuming their feed ad libitum. It was also observed that during this period there was a tendency for the mortality to be greater on the two lower levels of protein intake than on the higher levels. During the last 30 weeks of the experiment, mortality was due to scattered cases of neurolymphomatosis and injuries received in fights.

TABLE 3.—*Mortality of birds on the various diets during the periods indicated*[1]

LOTS FED AT 70 PERCENT OF NORMAL FEED INTAKE

Diet No.	Crude protein in diet	Birds that died during period from—							
		0 to 8 weeks	8 to 12 weeks	12 to 16 weeks	16 to 20 weeks	20 to 30 weeks	30 to 40 weeks	40 to 52 weeks	Total
	Percent	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
1	25	2	0	0	0	1	0	2+(2)	5+(2)
2	23	3	1	0	0	0	3	2+(2)	9+(2)
3	21	5	1	0	0	0	0	1+(1)	7+(1)
4	19	4	1	0	0	1	2	2+(2)	10+(2)
5	17	3	1	0	0	1	0	(2)	5+(2)
6	15	5	2	0	0	1	1	(4)	9+(4)
7	13	7	0	2	0	1	1+(1)	5	16+(1)
LOTS FED AD LIBITUM									
1	25	0	0	0	0	0	1	1+(2)	2+(2)
2	23	3	0	1	0	1	1+(2)	2+(2)	8+(4)
3	21	0	0	0	0	0	3+(1)	1+(3)	4+(4)
4	19	2	0	0	2	2	0	2+(2)	8+(2)
5	17	2	0	0	0	0	3	1+(3)	6+(3)
6	15	4	0	0	1	0	1+(1)	2+(1)	8+(2)
7	13	4	0	1	1	2	2	2+(1)	12+(1)

[1] Numbers in parentheses indicate birds that were killed by other birds.

LIVE WEIGHTS

The mean live weights of the birds in the several lots, together with the standard errors of the means, are given in table 4. The data show that at all ages the birds fed ad libitum weighed more than those fed the same diet with the intake limited to 70 percent of the normal. At 8 weeks of age, and through the sixteenth week, the weights of the birds in both groups that received 17 percent of protein in their diets were greater than the weights of birds that received 15 percent, and the birds that received 15 percent of protein weighed more than those that received 13 percent. At 16 weeks of age the birds that received 25 and 23 percent of protein were heavier than those that received 19 and 17 percent, which in turn were heavier than those that received 15 and 13 percent. The difference in live weight between the birds that received 13 percent of protein and those in the other lots was the greatest at this time. At 20 weeks of age the live weight of the birds remained in nearly the same relative order as at 16 weeks. By the end of the thirtieth week all the lots fed ad libitum, except the one receiving the diet containing 13 percent of

protein, had about the same average live weight. In the limited-fed lots differences in live weight in favor of the higher levels of protein intake persisted through the thirtieth week, but by the end of the experiment all the lots had approximately the same average live weight. By the end of the fortieth week, the birds on the lower levels of protein intake in the lots fed ad libitum had attained practically the same average live weights as those on the higher levels of protein intake.

TABLE 4.—*Mean live weights, and their standard errors, of birds on the various diets at the ages indicated*

Diet No.	Protein in diet	Mean live weight at end of—						
		8 weeks	12 weeks	16 weeks	20 weeks	30 weeks	40 weeks	52 weeks
	Percent	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
LOTS FED AT 70 PERCENT OF NORMAL FEED INTAKE								
1	25	600±24	1,161±38	1,709±36	2,038±41	2,574±67	2,837±72	2,761±73
2	23	570±25	1,074±39	1,608±38	1,973±42	2,428±69	2,571±75	2,743±76
3	21	573±22	1,078±33	1,611±32	1,896±36	2,409±59	2,657±63	2,639±65
4	19	535±24	986±38	1,470±36	1,815±41	2,304±61	2,544±72	2,584±73
5	17	570±22	1,010±34	1,480±33	1,885±37	2,377±61	2,631±65	2,639±67
6	15	490±24	917±38	1,403±36	1,775±41	2,338±61	2,711±72	2,740±73
7	13	390±26	710±41	1,089±39	1,484±44	2,244±72	2,536±78	2,707±79
LOTS FED AD LIBITUM								
1	25	669±23	1,256±35	1,893±34	2,318±38	3,088±62	3,142±67	3,104±69
2	23	678±26	1,227±41	1,862±39	2,256±44	3,001±72	3,241±78	3,111±79
3	21	651±28	1,121±42	1,734±41	2,287±46	3,094±77	3,120±81	3,054±83
4	19	599±24	1,135±36	1,777±35	2,261±39	3,034±65	3,085±70	2,967±71
5	17	655±26	1,193±41	1,692±39	2,010±44	3,067±72	3,105±78	3,004±79
6	15	559±24	1,092±36	1,637±35	2,041±39	3,004±66	3,141±70	3,000±71
7	13	467±25	773±39	1,160±38	1,672±42	2,724±69	3,110±75	3,024±76

Although the data in table 4 show that there were appreciable differences in mean live weight among the lots that received the diets of higher protein content, in many instances these differences were not statistically significant. However, at the age of 8 weeks and through the thirtieth week, there were statistically significant differences between the lots fed high- and those fed low-protein diets, regardless of whether the feed intake of the birds was limited or not.

FEED CONSUMPTION

The average cumulative feed consumption of thebirds at representative ages is given in table 5. In the lots fed ad libitum, the birds receiving the highest percentage of protein ate the most feed per week during the first 30 weeks of the experiment. During the last 22 weeks there was no consistent relationship between the protein content of the diet and the quantity of feed eaten by any of the lots of the ad libitum group.

TABLE 5.—*Cumulative feed consumption per bird on the various diets at the ages indicated*

Diet No.	Protein in diet	Average feed consumption during—						
		0 to 8 weeks	0 to 12 weeks	0 to 16 weeks	0 to 20 weeks	0 to 30 weeks	0 to 40 weeks	0 to 52 weeks
	Percent	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
LOTS FED AT 70 PERCENT OF NORMAL FEED INTAKE								
1	25	1,463	3,097	5,170	7,495	13,788	20,340	28,224
2	23							
3	21							
4	19							
5	17							
6	15							
7	13							
LOTS FED AD LIBITUM								
1	25	2,553	4,855	9,166	12,625	21,469	30,624	42,303
2	23	2,378	4,442	7,448	9,934	18,918	29,098	42,673
3	21	1,822	3,662	6,714	9,523	18,945	29,441	42,835
4	19	1,942	3,989	6,784	9,508	18,948	27,758	38,923
5	17	2,057	4,424	7,088	9,706	18,715	28,318	40,697
6	15	1,874	4,162	6,959	9,570	18,251	27,331	38,125
7	13	1,803	3,281	5,878	8,718	18,112	28,105	40,741

In contrast to the findings of McConachie and others (*7*), no abnormality in contour, texture, or barring of feathers was found in any lot, regardless of the level of protein intake. No bird in this experiment showed any symptoms of perosis.

ANALYSIS OF THE DATA

Trends in the growth of the birds and in the utilization of feed and protein are revealed more clearly by plotting the data after they have been smoothed by the method of moving averages. Figure 1 shows the smoothed average live weights, plotted against age in weeks, of the limited-fed lots and those fed ad libitum. In figures 1, 2, and 3 the curves for the lots fed diets containing 19 and 23 percent of protein have been omitted to prevent crowding the charts.

In the group that was fed ad libitum, as well as in the group that received only 70 percent of the normal level of feed intake, the higher the percentage of protein in the diets the greater were the average live weights of the birds up to the time they reached mature weight. The birds reached mature weight in the inverse order of the quantity of protein they had consumed. In each group the lots receiving 17 percent or more of protein did not differ markedly from one another but showed a distinct advantage over those receiving 15 percent of protein and a very pronounced advantage over those receiving 13 percent of protein. On all diets the birds fed at the limited level of feed intake ceased to grow when they were approximately 88 percent as heavy as those fed the same diets ad libitum.

The live weight of the chicks fed ad libitum were in the same order as the protein contents of their diets during the first 14 weeks of age. With the exception of the two lots fed 13 percent of protein in the diet, the gains per week of the chicks fed ad libitum and those fed a limited diet increased until the fourteenth week and then gradually declined until the forty-fourth week. The weekly gains of the two lots receiv-

ing 13 percent of protein did not reach a maximum until the seventeenth week, but the birds in these two lots gained more weight between the seventeenth and forty-fourth weeks than any other lots of their respective groups. Although their gains were not so uniform, the birds in the group fed ad libitum gained more rapidly in all cases than the birds fed the same percentage of protein in the limited-fed group. During the first 14 weeks it was found that the magnitude of the

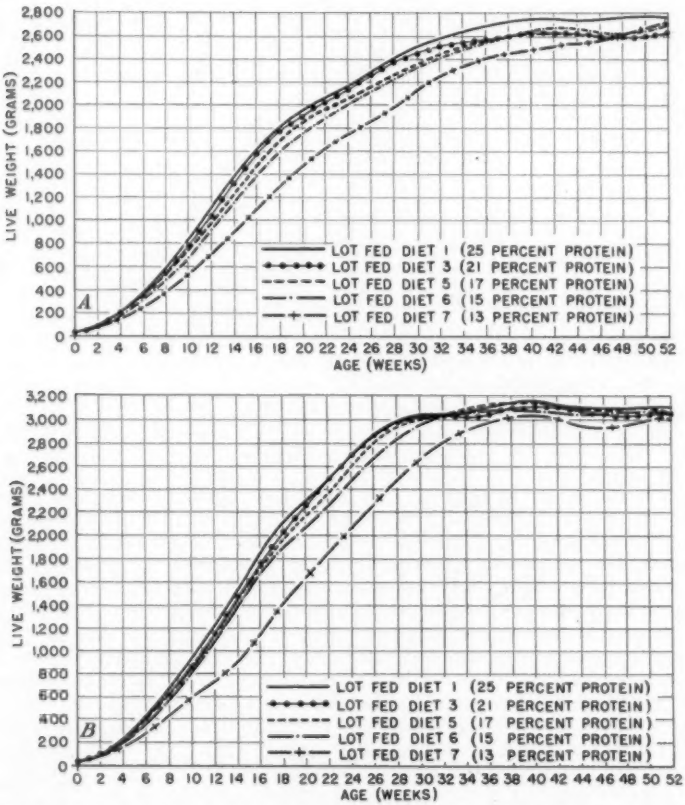
LIVE WEIGHT (GRAMS)
AGE (WEEKS)
A
B
LOT FED DIET 1 (25 PERCENT PROTEIN)
LOT FED DIET 3 (21 PERCENT PROTEIN)
LOT FED DIET 5 (17 PERCENT PROTEIN)
LOT FED DIET 6 (15 PERCENT PROTEIN)
LOT FED DIET 7 (13 PERCENT PROTEIN)

FIGURE 1.—Comparison of live weights of chickens, plotted against age, of the limited-fed (*A*) and of the ad libitum-fed (*B*) lots receiving various levels of protein in their diets. (Data smoothed by method of moving averages.)

average weekly gain in both groups was closely associated with the quantity of protein consumed; however, after the fourteenth week it was much less so.

The relative rates of gain were plotted according to the method used by Heuser and Norris (*4*) and compared with their published curves. The resulting curves resembled inverted curves of diminishing increment. The relative rates of gain reached zero at about the forty-fourth

week. The only irregularity was exhibited by the curve for the lot fed, ad libitum, the diet containing 13 percent of protein. The relative rates of gain for this lot showed a slight rise from the twelfth to the eighteenth week and a more gradual decline thereafter. The chief differences between diets were that during the first 10 weeks the higher the percentage of protein in the diet the higher the relative rate of gain and after the twentieth week the higher the percentage of protein in the diet the lower the relative rate of gain. The birds on limited feed made lower relative rates of gain during the first 2 weeks than those fed, the same diets ad libitum. Thereafter the relative rates of gain for birds on limited and on ad libitum feed of the same percentage of protein were almost identical. This indicates that as long as the diet is adequate for growth the type of curve followed by the relative rates of gain is not changed by the percentage of protein in the diet fed.

When average live weights are plotted against cumulative feed consumption, the resulting curves for the lots on limited-feed intake are one above another in the order of increasing percentage of protein in the diet, as shown by figure 2, *A*. However, figure 2, *B*, shows that when the same diets were fed ad libitum, the curves are one above another for the lots fed diets containing from 13 to 21 percent of protein, but the data show that the curve for the lot receiving 25 percent of protein would be below that for the lot receiving 21 percent of protein. Furthermore, the curve for the birds receiving 25 percent of protein is between those for lots receiving 15 and 13 percent of protein.

When average live weight was plotted against cumulative protein consumption (fig. 3, *A*, *B*), it became evident that the most efficient utilization of protein was by the birds receiving 15 percent of protein in each group. The figures indicate that the lots fed 15 percent of protein were followed, in the order of decreasing efficiency of protein utilization, by those that received 17, 13, 21, and 25 percent of protein in their diets. However, in the group fed a limited diet, the data in the next to the last column of table 6 indicate that the lot that received a diet containing 17 percent of protein was slightly more efficient in the utilization of protein than was the lot that received a diet containing 15 percent. This is also shown in figure 5, *A*. In the group fed ad libitum, the lot that received 25 percent of protein was strikingly less efficient in its use, in spite of its very rapid growth.

CALCULATED PARAMETERS AND CONSTANTS

The equation of the curve of diminishing increment may be written

$$W=A-Be^{-kF} \tag{1}$$

The first derivative of this equation is

$$\frac{dW}{dF}=kA-kW \tag{2}$$

If $\frac{dW}{dF}$ is defined as the efficiency of feed utilization, E, and if C is written in place of kA, the first derivative becomes

$$E=C-kW \tag{3}$$

which is the equation of a straight line.

A represents the maximum live weight attainable on a given diet at a given level of intake; B is equal to A minus the weight at the time of first feeding, and hence represents the maximum gain attainable; C is the gain in live weight that a unit of feed could produce if no feed were required for maintenance; k is the rate of decrease in efficiency.

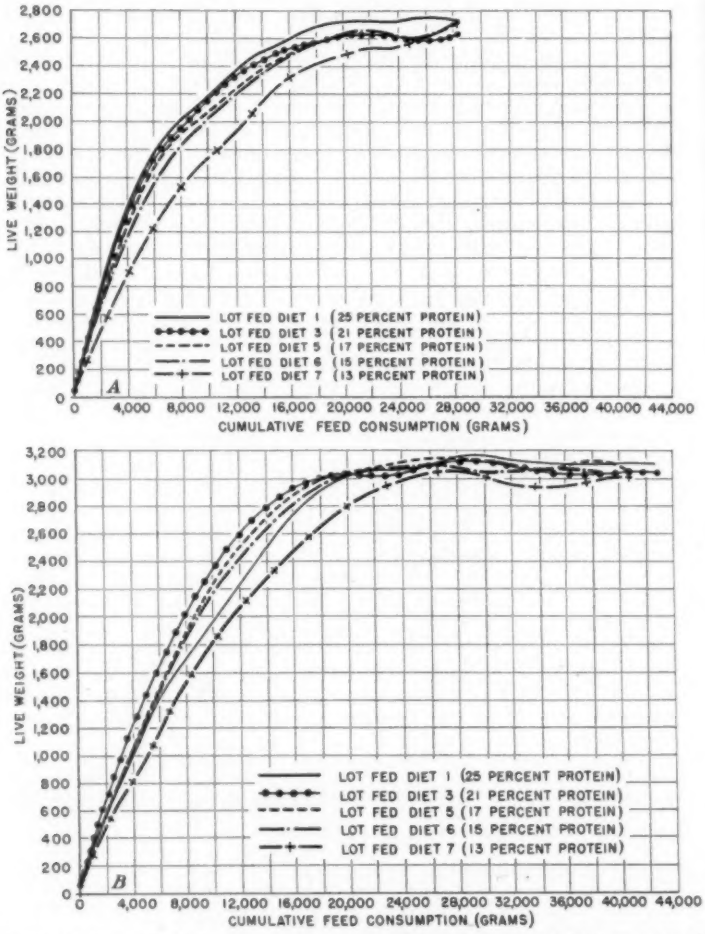
LIVE WEIGHT (GRAMS)
CUMULATIVE FEED CONSUMPTION (GRAMS)
LOT FED DIET 1 (25 PERCENT PROTEIN)
LOT FED DIET 3 (21 PERCENT PROTEIN)
LOT FED DIET 5 (17 PERCENT PROTEIN)
LOT FED DIET 6 (15 PERCENT PROTEIN)
LOT FED DIET 7 (13 PERCENT PROTEIN)
A
B

FIGURE 2.—Comparison of live weights of chickens, plotted against cumulative feed consumption, of the limited-fed (*A*) and of the ad libitum-fed (*B*) lots receiving various levels of protein in their diets. (Data smoothed by the method of moving averages.)

In other words, k is the amount by which the efficiency is decreased as the chicken gains one unit (1 g in this paper) of live weight. The quantity kW represents the loss in efficiency due to the maintenance requirement.

If E is divided by the percentage of protein in the diet, the result is the efficiency of protein utilization. Likewise if C is divided by the percentage of protein in the diet, the result (next to last column of table 6) is the gain in live weight that a unit of protein could produce if none were used for maintenance.

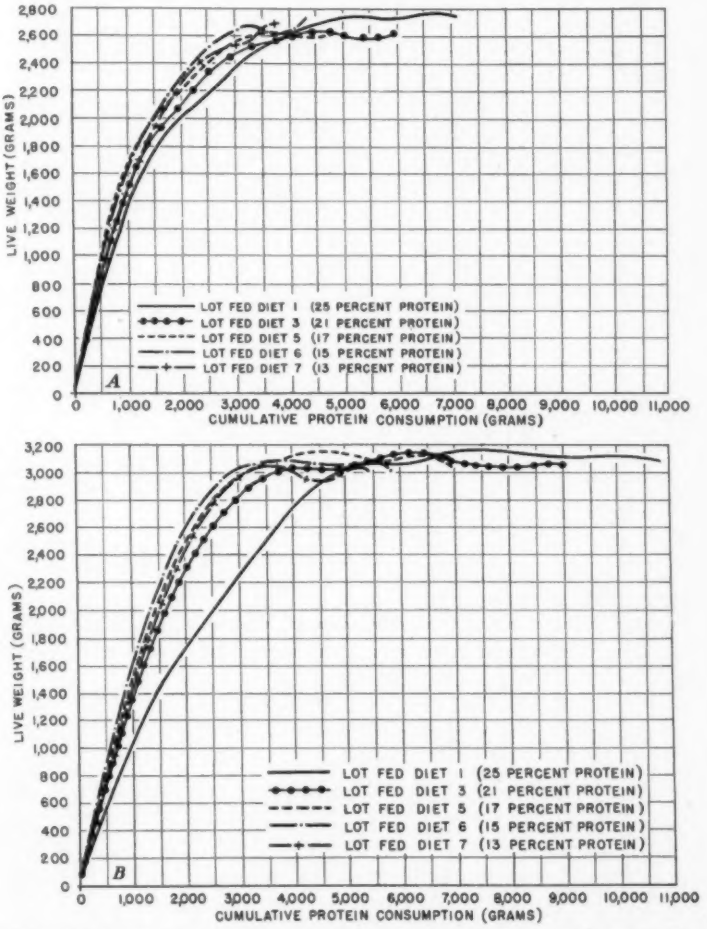

FIGURE 3.—Comparison of live weights of chickens, plotted against cumulative protein consumption, of the limited-fed (*A*) and of the ad libitum-fed (*B*) lots receiving various levels of protein in their diets. (Data smoothed by the method of moving averages.)

When $F=O$, E in equation (3) is equal to kB; that is to say, kB is the efficiency at first feeding, or the initial efficiency. R, the Spillman ratio, is the numerical value of e^{-k}, and is equal to the inverse ratio of the gain in live weight resulting from any two successive units of feed consumed.

The values of A, B, and k were determined by the method described by Hendricks (*3*). The adjustments suggested by Titus, Jull, and Hendricks (*17*) made no appreciable change in the values of the parameters when applied to these data and hence were not used. The numerical results of fitting equation (3) to the data on live weight and feed consumption are presented in table 6.

TABLE 6.—*Values of the parameters and derived constants of the live-weight and feed-consumption equations*

Diet No.	Protein in diet	A	Standard error of A	B	C	Standard error of C	1,000 k	Standard error of 1,000 k	R^2	Standard error of R	kB	C	Standard error of C
												Percentage of protein	Percentage of protein
	Percent	*Grams*	*Grams*	*Grams*									
LOTS FED AT 70 PERCENT OF NORMAL FEED INTAKE													
1	25	2,809	±85	2,771	0.4586	±0.0235	0.16329	±0.01098	0.999837	±0.000011	0.4525	1.8344	±0.0940
2	23	2,742	±78	2,702	.4417	±.0211	.16107	±.01015	.999839	±.000010	.4349	1.9204	±.0916
3	21	2,703	±81	2,664	.4316	±.0217	.15966	±.01057	.999840	±.000011	.4253	2.0552	±.1035
4	19	2,640	±88	2,602	.4191	±.0231	.15872	±.01153	.999841	±.000011	.4130	2.2058	±.1214
5	17	2,690	±74	2,652	.4129	±.0185	.15349	±.00916	.999846	±.000009	.4070	2.4288	±.1088
6	15	2,816	±111	2,778	.3604	±.0211	.12799	±.01046	.999872	±.000010	.3556	2.4027	±.1403
7	13	2,897	±194	2,858	.2767	±.0222	.09551	±.01192	.999904	±.000012	.2730	2.1285	±.1705
LOTS FED AD LIBITUM													
1	25	3,314	±119	3,276	0.3313	±0.0197	0.09996	±0.00786	0.999900	±0.000008	0.3275	1.3252	±0.0786
2	23	3,308	±119	3,269	.3544	±.0210	.10712	±.00840	.999893	±.000008	.3509	1.5408	±.0911
3	21	3,222	±95	3,185	.3895	±.0191	.12087	±.00776	.999879	±.000008	.3850	1.8548	±.0907
4	19	3,182	±121	3,144	.3636	±.0227	.11428	±.00946	.999886	±.000009	.3593	1.9137	±.1193
5	17	3,259	±222	3,221	.3656	±.0400	.11217	±.01642	.999888	±.000009	.3613	2.1506	±.2353
6	15	3,237	±158	3,198	.3406	±.0260	.10523	±.01081	.999895	±.000016	.3365	2.2707	±.1731
7	13	3,281	±148	3,243	.2659	±.0156	.08105	±.00696	.999910	±.000007	.2628	2.0454	±.1202

[1] The corresponding values, when the unit of feed consumption and live weight is 1 kg. are 0.8493, 0.8512, 0.8524, 0.8532, 0.8577, 0.8692, and 0.9089 for the lots fed at 70 percent of the normal feed intake, and 0.9049, 0.8984, 0.8862, 0.8920, 0.8939, 0.9001, and 0.9222 for the lots fed ad libitum.

Figure 4 illustrates, for each lot of the limited-fed and the ad libitum-fed groups, respectively, the linear relationship between E and live

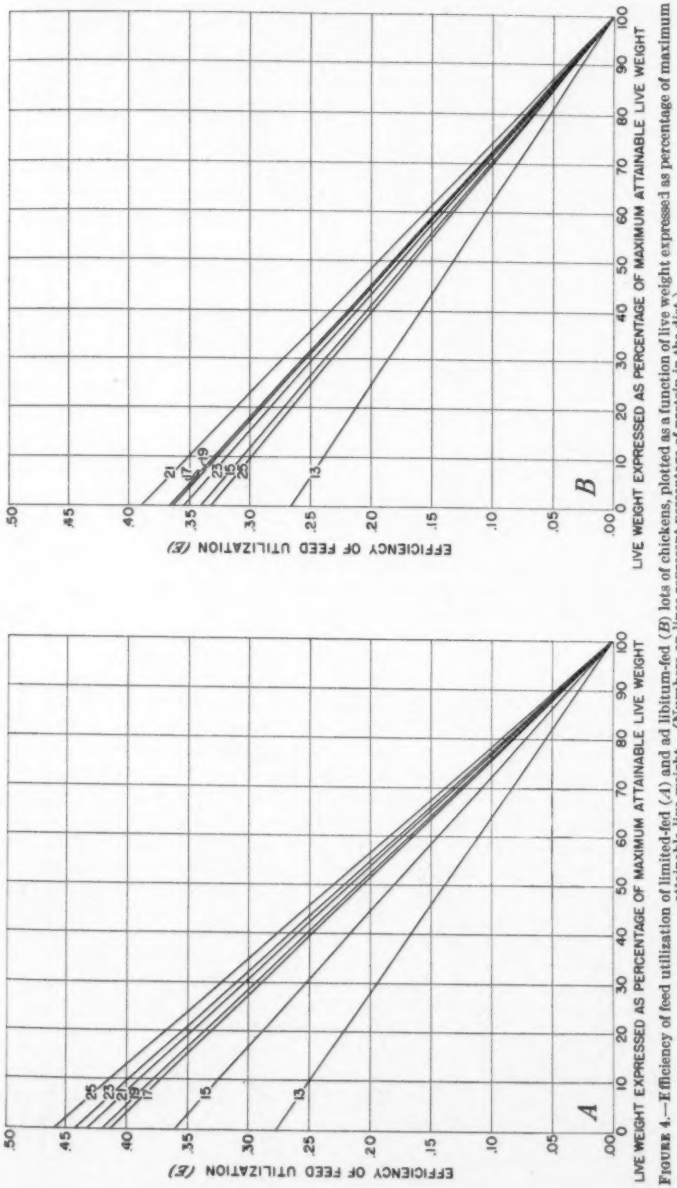

FIGURE 4.—Efficiency of feed utilization of limited-fed (*A*) and ad libitum-fed (*B*) lots of chickens, plotted as a function of live weight expressed as percentage of maximum attainable live weight. (Numbers on lines represent percentage of protein in the diet.)

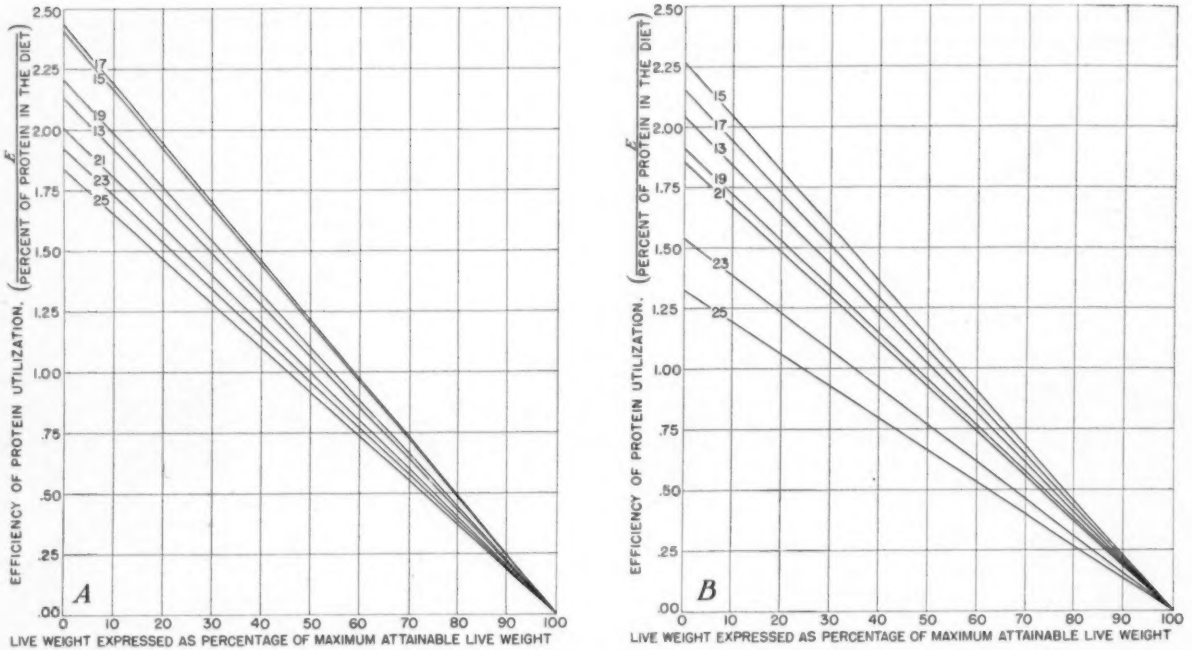

FIGURE 5.—Efficiency of protein utilization of limited-fed (*A*) and ad libitum-fed (*B*) lots of chickens, plotted as a function of live weight expressed as percentage of maximum attainable live weight. (Numbers on lines represent percentage of protein in the diet.)

weight expressed as percentage of A. The use of the percentages of maximum attainable live weight as abscissas in these figures is permissible because, as is indicated by the standard errors of A in table 6, no significant difference was found between the mature weights of any two lots in either group. However, the average value of A for the lots fed at 70 percent of the normal feed intake is significantly less than that for the lots fed ad libitum, and this difference should be kept in mind in comparing any lot in one group with any lot in the other group. In any case, the common point of zero efficiency established by using the percentage of maximum live weight instead of maximum live weight itself helps to show more simply the difference in efficiency of the lots within each group. Figure 5 illustrates a similar linear relationship between values of

$$\frac{E}{\text{percentage of protein in the diet}}$$

and the percentage of the maximum live weight. Figures 4 and 5 demonstrate that the efficiencies of feed or protein utilization at any given live weight are in the same relative order that they are at the initial live weight.

DISCUSSION

Mortality, which at times is the only clue to unknown nutritional deficiencies, was significantly associated with nutrition but twice in this experiment. In one instance limitation of the intake of feed (energy) was the cause; in the other, limitation of the quantity of protein.

Up to the time that the birds in each lot reached a mean live weight of 1,500 g, the birds in the limited-fed lots used their feed more efficiently than those fed the same diets ad libitum. However, the limited-fed lots required more time than the ad libitum-fed lots to reach any given mean live weight.

At the end of the experiment, the birds that had been fed at the 70-percent level of normal feed intake weighed, on an average, 88 percent as much as those fed the same diet ad libitum. Their feed consumption averaged 69 percent of that of the birds fed ad libitum, and thus their gross efficiency of feed utilization for the experiment was higher than that of the birds fed the same diets ad libitum. However, the birds in the group fed ad libitum reached an average weight of 2,700 g at 26 weeks of age, at which time they had eaten an average of 14,600 g of feed. The birds in the limited-fed group did not reach an average weight of 2,700 g until 48 weeks of age, by which time they had eaten an average of 26,300 g of feed. Hence, in spite of the higher gross efficiency of feed utilization of the limited-fed group, the birds fed ad libitum attained a weight of 2,700 almost twice as efficiently, in respect to feed consumed, as the limited-fed group. Obviously this was due to the fact that the birds in the limited-fed group had to be maintained 22 weeks longer than those in the other group before the average of 2,700 g was reached. This instance is an example of the fallacies that may be derived from reliable data when efficiencies of feed or protein utilization are compared at a given age.

As shown in table 5, during the first 16 weeks the two lots that were fed, ad libitum, diets containing 25 and 23 percent of protein—especially the one receiving 25 percent—ate much larger quantities of feed than any of the other lots. Since they grew but little faster than the lot fed 21 percent of protein, it seems quite possible that the high protein intake stimulated their appetites to such an extent that they consumed more feed than they could digest and absorb. Unfortunately, there is at present no definite way of testing the validity of this explanation because of the lack of information about the nitrogen metabolism of birds fed high protein diets ad libitum. It is worthy of note that according to the smoothed average-live-weight curves (fig. 1A) the birds in these two lots averaged more in live weight at all ages to maturity than did the birds in any of the more efficient lots. Thus, if rapid growth were the only consideration, the diets would increase in value in the order of their protein content, at least between the limits of 13 and 25 percent of protein. When feed costs must be considered, the use of 25 and 23 percent of protein fed ad libitum would not be justified on the basis of this experiment.

Since the values of C were derived by fitting the equation of the first derivative of the curve of diminishing increment to the observed data on feed consumption and live weight, it was possible to estimate the standard errors of these values of C. Examination of the standard errors of the values of C shows that, although there is a definite and regular upward trend in the value of C with each increment of protein for the limited diets, the differences are not statistically significant except between the two lowest levels of protein intake and between each of the two lowest levels and all others. In the lots fed ad libitum the value of C tended to increase as the protein in the diet increased from 13 to 21 percent, and then to decrease. In these same lots there were significant differences between the values of C for the following levels of protein intake: 21 and 25, 21 and 13, and 15 and 13. The deviation of C for the 19-percent level from its logical position between the values of C for the 17- and 21-percent levels is far from being statistically significant.

Since C represents the maximum value that E can take, the point at 0 live weight on each line in figure 4, A and B, is the C for that lot. From figure 4 it can be seen that at any specified live weight the efficiencies of feed utilization of a series of diets are in exactly the same relative position as the values of C, the maximum theoretical efficiency. This point is important since the erroneous impression is frequently gained, when efficiencies are plotted against age, that the lower protein diets are used more efficiently than the high protein diets in the later phases of growth. The reason for this impression is that birds on low protein diets usually do show more efficient use of feed at any given age after about the sixteenth week until their growth is completed. However, the fallacy in the reasoning is that, although the birds compared are of the same age, they are of different live weights and are in different phases of growth. When the birds on the low protein diets reach the same live weights as those with which they are compared on an age basis, it is found that they use their feed even less efficiently to gain any specified percentage of their maximum live weight.

In actual practice, these findings may not be of great importance, because the slight loss in efficiency resulting from feeding a lower protein diet during the later phases of growth may be offset by a compensating drop in the cost of a lower protein diet.

In comparing figure 4, *A* and *B*, it should be kept in mind that 100 percent of the maximum live weight in the limited-fed group is equal to an average of 88 percent of the maximum live weight of the group fed ad libitum.

Since the Spillman ratio, *R*, is equal to e^{-k}, the values of *R* fall in inverse order to the values of *k*. From this it follows that the more rapid the rate of decrease in efficiency the lower the corresponding Spillman ratio. In this study the low protein diets gave the slowest rate of decrease in efficiency because of their low initial efficiencies; also the 25-percent protein diet fed ad libitum had a low rate of decrease in efficiency for the same reason. It is evident that as the efficiency of utilization of the diets increased as a result of the increase in protein content, the magnitude of the Spillman ratios of the diets decreased. This is due to the fact that all lots of birds within each group reached approximately the same mean live weight at maturity.

For those who have followed the work of Spillman (Spillman and Lang (*14*)) and that of Titus, Jull, and Hendricks (*17*), this finding may seem to contradict previous results. When the same diet is fed at different levels of intake, as in the experiment made by Titus and associates (*17*), the initial efficiencies are nearly equal, but the final live weights for the different levels of intake are in the same order as the energy content of the feed consumed. Under such conditions the lots that attained the greatest average live weight would have the slowest rate of decrease in efficiency and hence the highest Spillman ratio. Thus it is possible for the Spillman ratio to be affected in one way when the feed intake is reduced but in the opposite way when the protein content is reduced. This statement is also true of *k* and *C*. Hence, any one of these constants by itself is of little value in evaluating the desirability of a diet. However, when *A*, *k*, and *C*, or *A*, *R*, and *C*, are taken into consideration at the same time they constitute an excellent basis for comparing the desirability of diets.

The utilization of the protein in the diet for growth is shown in a convenient form in figure 3, *A* and *B*. The facts shown by figure 3 are substantiated by the values of

$$\frac{C}{\text{percentage of protein in the diet}}$$

in table 6 and by figure 5, *A* and *B*, showing the straight-line relationship between

$$\frac{E}{\text{percentage of protein in the diet}}$$

and *W*, expressed as percentage of *A*. All evidence points to the same conclusion, namely, that with the exception of the lot fed the 13-percent protein diet, the efficiency of protein utilization by the lots in the ad libitum-fed group decreased with each increase in increment of protein. In the limited-fed group the same was true for the diets containing 17 percent or more of protein. It also follows that, since the more protein the birds ate the faster they grew, the faster the birds grew the less efficiently they used the protein of their diets.

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After mature weight had been reached, the birds on the diet that contained only 13 percent of protein maintained their live weight as well as those that received higher percentages of protein.

SUMMARY AND CONCLUSIONS

Comprehensive data were obtained on the relationship between the level of protein intake and live weight, feed utilization, and protein utilization of cross-bred male chickens. Rhode Island Red males and Barred Plymouth Rock females comprised the parent stock. Diets ranging from 13 to 25 percent of crude protein, by increments of 2 percent, were fed to seven pens of males ad libitum and to seven pens of males at 70 percent of an idealized intake for this cross for a period of 52 weeks. The weight of feed consumed per chicken per week and the live weight of the chickens at the end of each week were obtained.

Standard errors of the mean live weights were calculated at several ages, and the statistical significance of the differences between the means determined. The smoothed average live weights were plotted against age, feed consumption, and protein consumption.

The equation of the curve of diminishing increment was fitted to the data recorded for each of the 14 lots of chickens. Tabulations were made of the following parameters and their standard errors: A, the maximum live weight attainable; C, the efficiency of the diet when there is no maintenance requirement; B, the maximum gain attainable; k, the rate of decrease in efficiency; and R, the Spillman ratio.

Values of kB, the efficiency at first feeding, and

$$\frac{C}{\text{percentage of protein in the diet}},$$

the maximum gain theoretically possible per unit of protein consumed, were computed. Likewise the values of

$$\frac{E}{\text{percentage of protein in the diet}}$$

were plotted against W expressed as percentage of A.

When E was plotted against W expressed as percentage of A, it was found that the decline in efficiencies followed straight lines that reached a common zero point at A. Thus, it was shown that the efficiencies of feed utilization on the several diets at any specified live weight were in the same order as the values of C for those diets. In a similar manner the gains per unit of protein consumed on the different diets at a given live weight were shown to fall in the same order as the values of

$$\frac{C}{\text{percentage of protein in the diet}}$$

for those diets.

During the first 14 weeks the average live weights were found to be in the order of the quantity of protein consumed. After the fourteenth week the advantage in growth previously obtained by the birds on the higher protein diets was maintained to maturity but no further advantage was gained.

On the basis of feed consumed the chickens fed 21 percent of protein were the most efficient of the lots fed ad libitum, and those fed 25 percent of protein were the most efficient of the limited-fed lots.

On the basis of protein consumed, the chickens fed 17 percent of protein were the most efficient of the limited-fed lots and those fed 15 percent of protein were the most efficient of the ad libitum-fed lots.

Decrease in the efficiency of feed or protein utilization was found to be a linear function of live weights.

The more closely the birds approached their maximum live weight the smaller became the difference between the efficiencies of feed utilization.

All lots within the group fed ad libitum reached approximately the same live weight by the fortieth week. All lots in the limited-fed group reached approximately equal live weights by the fifty-second week. The more protein a lot of birds consumed the sooner the birds in that lot reached maturity.

The birds in the limited-fed lots used their feed more efficiently up to a live weight of 1,500 g, although they gained more slowly than those in the lots fed ad libitum. The high initial efficiencies of the former lots decreased more rapidly than the relatively low initial efficiencies of the latter lots. As a result, they required considerably more feed to attain an average weight of 2,700 g than did the lots fed the same diets ad libitum.

When the feed consumption was restricted to 70 percent of the normal intake, the Spillman ratio decreased as the level of protein intake increased. The result was the same when the birds were allowed to eat all they wanted, but in this case the decrease continued only until the level of protein intake was 21 percent, after which the Spillman ratio tended to increase.

For birds of the same age the more protein consumed per bird per week the greater is the average gain per week until the inflection point on the growth curve is reached.

Accurate comparison of the efficiencies of feed utilization is greatly simplified if efficiency is considered as a function of live weight rather than as a function of age.

For birds of the same live weight the relative position of the efficiencies of a series of adequate diets fed under identical conditions always tends to be the same.

When the diet contains all the factors necessary for growth, the curve followed by the relative rates of gain is similar in shape to an inverted curve of diminishing increment, and its general type is not changed by the protein content of the diet.

The constants of the curve of diminishing increment should be used in the combinations A, k, and C, or A, R, and C, but never singly, to evaluate a diet.

Of the diets used in this experiment, when consumed ad libitum, the one that contained 21 percent of protein was the most efficient for growth. It is therefore concluded that 21 percent of protein is near the optimum for growing chickens of all ages when the diet is fed ad libitum. In the case of the limited-fed group the efficiency of feed utilization continued to increase as the level of protein intake was increased from 13 to 25 percent.

After a bird has reached approximately half of its mature weight the difference in efficiency between a diet containing 21 percent of

protein and one containing 17 or even 15 percent of protein may be small enough to justify, in the interest of economy, the use of a diet containing the lower percentage of protein.

After maximum live weight has been reached, 13 percent of protein is adequate for the maintenance of male chickens.

LITERATURE CITED

(1) Carver, J. S., St. John, J. L., Miller, M. W., and Bearse, G. E.
1935. the comparative efficiency of various proteins for growing chicks. Wash. Agr. Expt. Sta. Bull 321, 26 pp., illus.

(2) Heiman, V.
1934. the relative vitamin g content of dried whey and dried skimmilk. Poultry Sci. 14: 137–146, illus.

(3) Hendricks, W. A.
1931. fitting the curve of the diminishing increment to feed consumption-live weight growth curves. Science 74: 290–291.

(4) Heuser, G. F., and Norris, L. C.
1931. the influence of the protein level on the rate of growth in chickens. Fourth World's Poultry Cong., London, Rept. Proc., pp. 328–342, illus.

(5) ——— and Norris, L. C.
1934. the influence of the protein level on the growth of chickens and its relation to subsequent behavior. 5th Cong. Mondiale di Pollicoltura Atti 2: 551–558, illus.

(6) Holst, W. F.
1927. a consideration of the protein requirements of growing birds. 3d World's Poultry Cong., Ottawa, Rept. Proc., pp. 183–187, illus.

(7) McConachie, J. D., Graham, W. R., Jr., and Branion, H. D.
1935. a study of the protein requirements of growing chicks. Sci. Agr. 15: 754–764, illus.

(8) Milne, H. I.
1932. protein requirements of growing chicks. Sci. Agr. 12: 604–620, illus.

(9) Morris, L.
n. d. high and low protein rations tested. Okla. Agr. Expt. Sta. Rpt. 1926–30: 99–102.

(10) Mussehl, F. E., and Gish, D. E.
1925. the protein requirement of growing chicks. Poultry Sci. 5: 20–23, illus.

(11) Norris, L. C., and Heuser, G. F.
1930. the relation of the protein requirements of chicks to the rate of growth. I. the quantity of protein required by chicks during early growth. Poultry Sci. 9: 378–392, illus.

(12) ——— Heuser, G. F., Ringrose, A. T., Wilgus, H. S., Jr., and Heiman, V.
1934. the vitamin-g requirement of poultry. 5th Cong. Mondiale di Pollicoltura Atti 2: 512–520.

(13) St. John, J. L., Carver, J. S., Johnson, O., and Brazie, D.
1934. optimum protein levels for chickens. 5th Cong. Mondaile di Pollicoltura Atti 2: 567–574, illus.

(14) Spillman, W. J., and Lang, E.
1924. the law of diminishing returns. 178 pp., illus., Chicago.

(15) Swift, R. W., Black, A., Voris, L., and Funk, E. M.
1931. the optimum protein content of rations for growing chicks. Poultry Sci. 10: 288–298, illus.

(16) Tepper, A. E., Charles, T. B., and Reed, F. D.
1933. protein levels in battery brooding chicks. N. H. Expt. Sta. Cir. 40, 7 pp.

(17) Titus, H. W., Jull, M. A., and Hendricks, W. A.
1934. growth of chickens as a function of feed consumption. Jour. Agr. Research 48: 817–835, illus.

(18) Wilgus, H. S., Jr., Norris, L. C., and Heuser, G. F.
1935. the relative protein efficiency and the relative vitamin g content of common protein supplements, used in poultry rations. Jour. Agr. Research 51: 383–399, illus.

ENERGY REQUIREMENTS OF SWINE AND ESTIMATES OF HEAT PRODUCTION AND GASEOUS EXCHANGE FOR USE IN PLANNING THE VENTILATION OF HOG HOUSES [1]

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INTRODUCTION

A few years ago, the writers (*24*)[2] published estimates of the daily output of heat, carbon dioxide, and water by various kinds and conditions of poultry for the use of the agricultural engineer in planning the ventilation of poultry houses. The present paper is an extension of this line of work to swine, supplementing and, to some extent, confirming the somewhat fragmentary estimates previously made by Armsby and Kriss (*2*).

The data presented in this paper are also of significance to the problem of the energy requirements of growing, gestating, and lactating swine. They are the result of an analytical study of the energy requirements of swine for each of the various animal functions as revealed by published information, and of an integration of these requirements to apply to pigs of any particular age (or weight) and condition. This method of study, involving the differentiation of animal functions for separate measurement and study and the integration of these measurements for application to any particular animal, is scientifically sound and, because of its flexibility, is widely applicable. If at this writing the method cannot be followed through with perfect assurance with reference to any particular species of animal, the difficulties in so doing will be perfectly obvious and will indicate clearly the most significant problems for future research.

METHODS OF ESTIMATION

The general procedure followed in estimating the energy requirements of swine has been to factor out and to assess as accurately as possible all of the items contributing to the expenditure and storage of energy, and then to integrate these factors for pigs of different weights and condition. Estimates of the net availability of the metabolizable energy of food permit the conversion of net energy to metabolizable energy values, and from the latter, dry-matter requirements may be estimated for some more or less typical ration. Summation of energy expenditures (basal metabolism, muscular activity, heat increment of feed) leads to an estimate of heat production, and from the latter estimates of the probable output of carbon dioxide and of the usual and maximal output of water vapor may be made. The sources of information in all these estimations will first be considered.

[1] Received for publication December 11, 1937; issued June 1938.
[2] Italic numbers in parentheses refer to Literature Cited, p. 827.

Basal metabolism.—The basal metabolism of pigs of different weights has been quite extensively studied by Brody (*7*) and by Deighton (*10*), using castrated male pigs and female pigs. The measurements obtained have been analyzed statistically by Brody. For pigs weighing from 50 to 275 kg, the equations fitted to the two sets of data give predictions that agree very closely. For pigs weighing less than 50 kg., Brody's data are too few to confirm or refute the data of Deighton. In estimating the basal metabolism of castrated male and female pigs for the purposes of this report, the prediction equation derived by Brody from Deighton's data have been used. These equations are—

For pigs weighing less than 50 kg:

$$\frac{Q}{m}=68e^{-0.049m}+22.$$

For pigs weighing more than 50 kg:

$$\frac{Q}{m}=34e^{-0.011m}+10$$

where Q is the basal heat production in calories per day, m is the weight of the pig in kilograms, and e is the base of natural logarithms.

For uncastrated male pigs, the data of Brody appear to be the only information available, the prediction equation being

$$\frac{Q}{m}=34e^{-0.0162m}+17.$$

Available information does not indicate any considerable differences in the basal metabolism of pigs due to breed or type, Deighton's data (*10*) notwithstanding.

Muscular activity.—The maintenance energy requirement of an animal includes, besides the basal expenditure, a quota of energy expended in a degree of muscular activity presumably more or less characteristic of the species. The size of this quota has not been measured with any considerable degree of accuracy either for the pig or for other farm animals, although the information concerning this energy quota and its variation with age, sex, degree of confinement, environmental conditions, etc., would possess much scientific and practical importance. Wood (*36*) has attempted an indirect determination of this quota by deducting from the estimated net energy intake of various groups of growing pigs the energy estimated to have been expended in the basal metabolism and the energy estimated to have been stored in the tissues. While the results vary greatly, they led Wood to the conclusion (*36, p. 439*) that—

> the normal daily expenditure of energy on muscular effort by a well-fed and tended Large White pig is in the neighborhood of 1000 calories per day, which is equivalent to 1 lb. per day of any standard mixed pig meal. This figure varies widely from week to week according as the conditions induce more or less muscular movement. If the animals are quiet and contented it is low. If they have to scramble for room at the trough or if they are distressed by hot weather it is high. As it yields no return at all in the form of increased live weight, the importance of keeping it low by good management is strongly emphasized.

The daily expenditure of energy for muscular activity appeared to be as large for the little pig as for the big one.

While it is difficult to point out any gross error in these calculations of Wood, there is very good reason to believe the estimate of the activity energy quota is considerably too high. Mitchell and Hamilton (*23*) found that 1 pound a day per 100 pounds live weight of a ration composed of corn, middlings, and tankage was adequate to maintain pigs weighing 225 pounds in energy equilibrium under the practical conditions of dry-lot feeding. For pigs weighing 50 to 70 pounds, 1.5 pounds of the ration used was required per 100 pounds live weight. Furthermore, the determined metabolizable energy intake required for maintenance of energy equilibrium (1,015 cal.) exceeded the estimated basal metabolism (841 cal.) by only 174 cal. for 50-pound pigs, and by only 1,295 cal. (3,445−2,150) for 225-pound pigs. Assuming a net availability of the metabolizable energy of 80 percent for maintenance (see below), leaves no quota of energy for activity for the 50-pound pigs and only 600 cal. for the 225-pound pigs.

Breirem (*6*), working in Møllgaard's laboratory, estimates the maintenance requirement of pigs from the equation

$$M=2{,}101\left(\frac{W}{100}\right)^{5/6}$$

where M is the daily requirement of net energy (for pigs, not for cattle, as in the original formula; the constant $2{,}101=1{,}450\div 0.69$) and W is the body weight of the pig in kilograms. This formula, obtained from experimental data on bacon-type pigs, gives very nearly the same values for maintenance as Brody's equations (based on Deighton's data) give for basal metabolism (table 1).

TABLE 1.—*The maintenance requirement of energy for pigs by different standards*

Weight of pig (pounds)	Daily basal metabolism (Deighton)	Daily maintenance requirement according to—			Weight of pig (pounds)	Daily basal metabolism (Deighton)	Daily maintenance requirement according to—		
		Breirem	Edin and Helleday				Breirem	Edin and Helleday	
	Calories	*Calories*	*Feed units*	*Calories*		*Calories*	*Calories*	*Feed units*	*Calories*
50	1,007	921	0.53	1,167	150	1,775	1,695	1.09	2,400
75	1,185	1,154	.73	1,607	175	1,921	1,847	1.13	2,488
100	1,332	1,353	.90	1,982	200	2,045	1,989	1.12	2,466
125	1,544	1,532	1.02	2,246	225	2,150	2,124	1.07	2,356

Breirem adds to his maintenance quota of energy, a quota for production in order to obtain a total requirement. Thus, in this scheme, no provision is made for a quota of energy dependent upon muscular activity outside of that contained in the maintenance requirement.

From Swedish cooperative feeding tests, Edin and Helleday (*12*) estimate the maintenance requirements of growing swine in feed units by the following equation:

$$y=2.72+0.0164x$$

in which y=feed units required per 100 kg body weight and x=body weight in kilograms. The feed units so computed are given in table 1. In converting these feed units into net energy, use is made (1) of Popoff's (*26*) recent determination of the net energy value of barley for the

fattening of swine, i. e., 1,960 cal. per kilogram, and (2) of Breirem's finding (*6*) that in swine the net energy of a feed for fattening is only 89 percent of its net energy for maintenance. On these assumptions, 1 kg of barley, or 1 feed unit, would have a net energy value for maintenance of 2,202 cal. The net energy requirements for the maintenance of swine thus computed from Edin and Helleday's equation are given in column 5 of table 1. They show increments over the Deighton basal values ranging from 160 to 702 cal. daily, or, in percent of the basal, from 10 to 49, averaging about 30.

Rapport, Weiss, and Csonka (*27*) noted increases of heat production of 12 percent when a pig was restless in the respiration chamber, and an increase of only 35 percent when "much movement was noted."

Contrary to the conclusion of Wood, it appears that the energy expenditure by swine in muscular activity is a comparatively small item. For the purposes of these estimates, it has been assumed that this quota equals 20 percent of the basal energy expenditure for swine of all ages and conditions. Most certainly the information on this point needs confirmation and supplementation.

Growth and fattening.—The rate of body weight gain by growing and fattening pigs has been taken from Missouri (*15*) and Ohio (*28*) records and represents a liberal system of feeding. According to Hogan and his coworkers (*15*), there is no difference between the bacon and lard types of pigs as regards rate of gain in the feed lot or composition of gain on the same ration, while later Illinois (*9*, *23*) results indicate the same to be true for different types of Poland China pigs, except for a possible inferiority of the Chuffy type with respect to rate of gain. Type differences relate to the distribution of fat on the carcass, not to the fat content of the added tissue.

While type of pig has not been shown to affect energy requirements, the method of feeding employed will determine to some extent not only the rate of growth and fattening, but also the composition of the gains put on. Hence, estimates were made separately for what has been called American feeding practice and English feeding practice. For the latter, the data of Wood (*36*) on rate of gain and the composition of gain have been used. However, Whetham's (*31*) results indicate a more even rate of gain of pigs shown at the Smithfield carcass competitions, averaging 1.22 pounds per day. For the estimates of composition of gain according to American feeding practice, the data of Hogan and his coworkers (*15*) and of Mitchell and Hamilton (*23*) have been considered. The estimates finally used for the energy value of a pound of gain at the various body weights are given in table 2.

TABLE 2.—*Estimated energy content of a pound of gain by pigs of increasing body weight*

Body weight (pounds)	Energy content of gain per pound	Body weight (pounds)	Energy content of gain per pound	Body weight (pounds)	Energy content of gain per pound	Body weight (pounds)	Energy content of gain per pound
	Calories		*Calories*		*Calories*		*Calories*
2.5	500	75	1,625	200	2,400	500	3,950
5	750	100	1,750	225	2,600	600	4,050
10	1,000	125	1,850	250	2,850		
25	1,250	150	2,025	300	3,200		
50	1,500	175	2,200	400	3,750		

Pregnancy.—In estimating the requirements of a pregnant 300-pound gilt and a 400-pound sow, it has been assumed that the former would be fed to gain 1 pound daily and the latter 0.6 pound. It has been further assumed that, except for the increasing weight of the products of conception, the energy content of the gain in body weight would contain 2,400 and 3,000 cal. per pound, respectively. The gains in weight of the products of conception throughout the gestation period of 16 weeks, as well as the energy content of these products, have been taken from the publication of Mitchell, Carroll, Hamilton, and Hunt (*21, table 16*). The estimates relate to an average litter of eight pigs.

Lactation.—In estimating the energy requirements of a lactating 400-pound sow, it is assumed that she would be maintained in weight and energy equilibrium throughout an 8-week lactation period. This ideal would probably be only rarely realized in practice, and to the extent that practice falls short of this ideal, the estimates of probable output of heat, water vapor, and carbon dioxide are too high. The daily yield of milk is estimated from the compilation of data published by Bonsma and Oosthuizen (*3*), while the energy content of sow's milk, 654 cal. per pound, is computed from the analyses of Hughes and Hart (*17*).

Net energy required.—The total requirement of net energy is equal to the sum of all expenditures of energy (basal metabolism, muscular activity) with the exception of the heat increment due to feed, and all storages of energy in growth, fattening, gestation, and lactation.

Metabolizable energy required.—In estimating the requirements of metabolizable energy from the expenditures of energy in the basal metabolism and in muscular activity, and from the storages of energy, it was assumed that the metabolizable energy was 80 percent net available when used for maintenance and milk production, and 70 percent net available when used for growth and fattening and for intrauterine growth.

These values represent compromises between more or less discordant data. From respiration experiments on swine carried out in Møllgaard's laboratory, Breirem (*6*) concludes that the metabolizable energy of the rations fed was 81 percent net available for maintenance. Fingerling (*13*) obtained an average utilization of 75 percent for the metabolizable energy of the basal rations used in his respiration experiments on swine. These rations were all supermaintenance with respect to energy.

The data on the utilization of energy for fattening are much more numerous. From a number of German experiments on swine, Armsby (*1*) has computed the net availability of the metabolizable energy of swine feeds for fattening, the estimates varying from 69 to 85 percent and averaging 79. Fingerling (*13*) found that the metabolizable energy of potato starch added to supermaintenance basal rations was utilized to an average extent of 83.5 percent. Breirem (*6*) obtained a net utilization of only 70 percent of the metabolizable energy intake of swine for growth and fattening. Feeding and slaughter tests on growing swine at the Illinois Agricultural Experiment Station (*23*) indicated an average net availability of 63 percent of the metabolizable energy consumed above maintenance. Similar experiments of Popoff (*26*), in which barley was added to a basal ration permitting some fattening, were interpreted to mean that barley possesses a net energy

value of 97.8 therms per 100 pounds of dry matter. Assuming the metabolizable energy of barley to be 151 therms per 100 pounds of dry matter (*1*, *table 204*), the net availability of the metabolizable energy amounts to 65 percent. From Wellmann's feeding and slaughter experiments (*30*) on eight suckling pigs, the writers have computed an average net availability of the metabolizable energy of 84.5 percent for both maintenance and growth.

Dry matter required.—In converting the requirements of metabolizable energy into terms of dry matter, the latter has been assumed to contain 3,350 cal. per kilogram; this value refers in particular to a ration of corn, tankage, and middlings (*23*).

Total heat produced.—The total heat produced by a pig of any age or condition is the sum of the heat expended in maintenance (basal metabolism and muscular activity) and the heat increment due to feeding. The latter increment is the difference between the requirement for metabolizable energy and that for net energy.

Output of water vapor.—The output of water vapor is computed for all pigs under two sets of conditions. When the temperatue of the environment is equal to or is above the body temperature of the pig, i. e., 102.5° F., all of the body heat will be lost in the evaporation of water. In this extreme case, the daily loss of water vapor in grams will be equal to the daily heat production in calories divided by 0.58, the heat of vaporization of 1 g of water at approximate skin temperature, 85° F. or so. The percentage of the total heat output lost in the vaporization of water may vary widely from this maximum as environmental conditions vary. It will decrease to zero whenever the relative atmospheric humidity equals 100 percent. At low temperatures it will be small and will increase along a logarithmic curve (*24*, *p. 737*). It is commonly considered that under usual conditions animals lose about 25 percent of their heat in the vaporization of water, and this has been assumed in the computations given below, particularly since Wierzuchowski and Ling (*32*) as well as Rapport, Weiss, and Csonka (*27*) have shown that pigs in the respiration chamber excrete 20 to 25 percent of their heat in the vaporization of water.

Output of carbon dioxide.—Although extremely high respiratory quotients (1.40 to 1.58) have been noted for pigs during short periods of time in the absorptive period (*32*), the 51 respiration experiments of Breirem (*6*) on pigs fed high- and low-protein rations, indicate a range in respiratory quotients of only 0.99 to 1.25, averaging about 1.1, for 24-hour periods. An average respiratory quotient of 1.1 has been assumed in estimating the carbon dioxide production of pigs from their production of heat. At this respiratory quotient 1 liter of oxygen possesses a calorific value of 5.156 cal. It is evident that the output of carbon dioxide indicated in the tables may at times be exceeded by 40 to 50 percent.

Estimation of critical temperature.—In estimating the critical temperature of pigs of any particular weight and condition, that is, the temperature below which extra heat must be generated to maintain body temperature, the critical temperature of the fasting pig is taken at 68° F., on the basis of the experiments of Capstick and Wood (*8*). The rise in heat production below the critical temperature seems to proceed along a straight line (*8*) and to follow Newton's law of cooling bodies (*22*, *p. 556*). Hence the extra heat required per degree Fah-

renheit drop in environmental temperature to maintain the body temperature of the pig is given in each case by the equation

$$k=\frac{BM}{34}$$

where BM is the basal heat production per day, and 34 is the difference between the body temperature of the pig, 102° F., and the assumed critical temperature under basal conditions, 68°. The heat available to meet this added demand is provided by muscular activity and by the heat increment of feeding. Hence, the sum of these two sources of heat, divided by k as above determined, gives the range in environmental temperature below the critical temperature of fasting within which the available supply of heat is adequate to maintain body temperature. The lower limit of this range is therefore the critical one under the specified conditions of activity and feeding.

It is of course true that calculations of this character are not particularly reliable, because the critical temperature of an animal will be lowered by any condition that increases heat production (activity, feeding) or insulates the animal from its environment (increasing fatness, hair growth); it will be raised by any condition that decreases heat production (sleep) or increases heat emission at low temperatures (drafts, increasing humidity). Deighton (*10*) has obtained indications of a much lower critical temperature (16° C.) in a Middle White pig than that more accurately measured by Capstick and Wood (*8*). Since the pig used in the latter study varied in weight from about 200 to 400 pounds during the period of observation, the calculated critical temperatures for pigs within this weight range may be more significant than those calculated for lighter or heavier pigs.

Estimates for boar pigs.—The data reported in the tables of this paper relate to female pigs and castrated male pigs, the assumption being that females and unsexed males are similar with reference to the physiological measurements considered (*23*). No data on boar pigs with reference to muscular activity and composition of gains were found in the literature. One comparison of the growth rates of male and female pigs was discovered (*33*), indicating a much more rapid growth for the former. Brody has demonstrated increases in basal metabolism of 10 to 38 percent in male pigs over females of the same body weight, the percentage sex increment increasing with increasing weight. Popoff's experiments (*26*) on the net energy of barley was carried out on boar pigs. However, these bits of information are inadequate to permit estimations for boar pigs of the energy requirements and the heat and gaseous exchange.

Undoubtedly the full male pig is distinguished from the female pig of equal weight by a more intense basal metabolism, a greater rate of growth, and a lower energy content of gains; possibly by a greater degree of muscular activity. Thus, the rate of growth of castrated male pigs may be greatly increased by administering by mouth a testicular preparation (*20, 34*). The requirements of the boar for energy are probably greater, as would be its production of heat, carbon dioxide, and water vapor.

THE RESULTS OBTAINED

The results of the estimations above described are collected in tables 3, 5, and 6.

TABLE 3.—*Daily food requirements, heat production, and gaseous exchange of growing and fattening female and castrated male pigs, according to American and English feeding practices*

AMERICAN PRACTICE

Body weights (pounds)	Average daily gain	Total net energy required	Metabolizable energy required	Dry matter required	Feed[1] economy of gains	Total heat produced	Water vaporized		Carbon dioxide produced	Estimation of critical temperature		
							Under ordinary conditions	At 103° F. and above		Extra heat available	Heat required per degree drop below 68.7° F.	Critical temperature
	Pounds	*Calories*	*Calories*	*Grams*	*Pounds*	*Calories*	*Grams*	*Grams*	*Liters*	*Calories*	*Calories*	*° F.*
2.5	0.20	250	330	99	1.2	200	86	345	43	100	.....	.....
5	.30	450	610	182	1.5	380	164	655	81	200	.....	.....
10	.40	820	1,100	328	2.0	800	483	1,379	171	350	.....	.....
25	.60	1,575	2,110	630	2.6	1,350	582	2,328	288	670	20	35
50	.85	2,400	3,200	955	2.8	1,980	854	3,414	422	1,010	29	34
75	1.02	3,200	4,500	1,343	3.3	2,550	1,099	4,397	544	1,350	33	28
100	1.20	4,000	5,600	1,672	3.5	3,050	1,315	5,259	651	1,700	39	25
125	1.40	4,700	6,600	1,970	3.5	3,550	1,530	6,121	757	2,000	45	24
150	1.55	5,500	7,600	2,269	3.7	4,000	1,724	6,897	853	2,320	51	23
175	1.70	6,200	8,500	2,537	3.7	4,450	1,918	7,672	949	2,650	55	21
200	1.78	6,900	9,500	2,836	4.0	4,940	2,129	8,517	1,054	2,940	58	18
225	1.85	7,600	10,500	3,134	4.2	5,350	2,306	9,224	1,141	3,210	61	16
250	1.85	8,300	11,300	3,373	4.6	5,700	2,457	9,828	1,216	3,500	62	13
300	1.80	9,250	12,700	3,791	5.3	6,200	2,673	10,690	1,323	3,900	68	12
400	1.60	9,200	12,500	3,731	5.8	6,500	2,802	11,207	1,387	3,850	76	18
500	1.33	8,675	11,650	3,478	6.5	6,600	2,845	11,379	1,408	3,650	86	26
600	1.00	8,000	10,700	3,194	8.0	6,700	2,888	11,552	1,429	3,350	96	30

ENGLISH PRACTICE

2.5	0.15	268	359	107	1.8	209	90	360	45	111	.....	.....
5	.23	444	593	177	1.9	375	162	647	80	187	.....	.....
10	.37	719	954	285	1.9	651	280	1,122	139	304	.....	.....
25	.65	1,285	1,688	504	1.9	1,233	531	2,126	263	541	20	42
50	.97	1,887	2,462	735	1.9	1,783	768	3,074	380	776	29	42
75	1.25	2,422	3,207	957	1.9	2,207	951	3,805	471	1,022	34	39
100	1.50	3,098	4,141	1,236	2.1	2,641	1,138	4,553	563	1,309	39	35
125	1.73	3,929	5,282	1,577	2.3	3,206	1,382	5,528	684	1,662	45	32
150	1.95	5,035	6,813	2,034	2.6	3,908	1,684	6,738	834	2,133	52	27
175	2.03	5,756	7,812	2,332	2.9	4,361	1,880	7,519	930	2,440	56	25
200	1.95	6,354	8,639	2,579	3.3	4,739	2,043	8,171	1,011	2,694	59	23
225	1.75	6,955	9,475	2,828	4.0	5,100	2,198	8,793	1,088	2,950	62	21
250	1.55	8,115	11,113	3,317	5.4	5,688	2,452	9,807	1,214	3,446	65	16

[1] Expressed in pounds of food (containing 12 percent of moisture) required per pound of gain.

An important test of these more or less uncertain estimates of the nutritive requirements of pigs is to compare them with estimates and feeding standards proposed on the basis of other evidence. Also, for the growing and fattening pigs, the feed economy of gains has been computed in the ordinary way, after converting the dry matter requirements into requirements for feed containing 12 percent of moisture. These ratios of feed to gain are given in table 3. For

the feeding according to American practice, the ratios are those ordinarily obtained, but for the feeding according to English practice, the ratios seem low, the fattening process being much slower.

TABLE 4.—*Comparions of estimated feed requirements of growing and fattening pigs with various proposed standards*

Body weight (pounds)	Estimated feed requirements [1]		Proposed feeding standards of others for comparison			
	American practice	English practice	Brierem [2]	Edin and Helleday [2]	Hansson and Bengtsson [2]	Morrison [1] (minimum values)
	Kilograms	*Kilograms*	*Feed units*	*Feed units*	*Feed units*	*Kilograms*
50	1.1	0.8	0.9	1.2	1.2	1.1
75	1.5	1.1	1.3	1.7	1.7	1.5
100	1.9	1.4	1.6	2.2	2.1	1.9
125	2.2	1.8	1.9	2.5	2.5	
150	2.6	2.3	2.2	2.8	2.8	2.5
175	2.9	2.6	2.5	3.1	3.0	
200	3.2	2.9	2.8	3.3	3.2	3.0
225	3.6	3.2	3.1	3.5		
250	3.8	3.8				3.4
300	4.3					3.7

[1] Expressed in terms of feed containing 12 percent of moisture.
[2] Expressed in feed units of 1 kg of concentrate feed mixture.

In table 4 the estimated requirements (in kilograms) of growing and fattening pigs for feed containing 12 percent of moisture are compared with the recommendations of Breirem (*6*), Edin and Helleday (*12*), and Hansson and Bengtsson (*14*) expressed in Scandinavian feed units, and with the lower values in the feeding standard of Morrison (*25*), expressed in kilograms of feed containing 12 percent of moisture. All the values given are mutually comparable.

The agreement between the proposed estimates and those made by other investigators is in general remarkably good. The recommendations of Breirem check best the estimates for the English system of feeding, while the other recommendations check best with those for the American system, this being true in particular for the Morrison standard up to 200 pounds body weight.

From Breirem's (*5*) feeding experiments with breeding sows, it may be calculated that a 300-pound gilt would require 1.1 feed units daily for maintenance and 0.5 feed unit additional for the requirements of pregnancy. This may be compared with the average estimate of about 1.8 kg of dry matter daily (table 5). In the case of a 400-pound sow, Breirem's estimate would call for 1.85 feed units daily, while the estimates of table 5 range from 1.4 to 1.9 kg of dry matter daily. For a 300-pound gilt Morrison (*25*) recommends 2.0 kg of dry matter daily, and for a 400-pound sow, 2.1 kg.

For lactating sows, Breirem (*4*) recommends 0.5 to 0.6 feed unit per pig per day above the needs of the sow. In the case of a 400-pound sow suckling eight pigs, the average daily requirement would be 5.75 feed units, a figure greatly in excess of the dry-matter requirements estimated in table 6, which range from 2.4 to 3.2 kg daily, equivalent to 2.7 to 3.6 kg of feed containing 12 percent of moisture. Morrison recommends a minimum of 4.3 kg of dry matter per day for a 400-pound sow nursing a litter.

TABLE 5.—*Daily food requirements, heat production, and gaseous exchange of a pregnant 300-pound gilt throughout gestation, fed to gain 1.0 pound daily, and of a pregnant 400-pound sow throughout gestation, fed to gain 0.6 pound daily*

300-POUND GILT [1]

At end of gestation week—	Body weight	Total net energy required	Metabolizable energy required	Dry matter required	Total heat produced	Water vaporized		Carbon dioxide produced
						Under ordinary conditions	At 103° F. and above	
	Pounds	*Calories*	*Calories*	*Grams*	*Calories*	*Grams*	*Grams*	*Liters*
0	300	5,380	7,171	2,141	4,671	2,013	8,053	996
1	307	5,257	6,992	2,088	4,637	1,999	7,995	989
2	314	5,159	6,848	2,044	4,612	1,988	7,952	984
3	321	5,068	6,714	2,004	4,591	1,979	7,916	979
4	328	4,987	6,595	1,969	4,574	1,971	7,886	976
5	335	4,910	6,481	1,935	4,559	1,965	7,860	973
6	342	4,832	6,366	1,900	4,544	1,958	7,834	969
7	349	4,765	6,266	1,870	4,532	1,953	7,814	967
8	356	4,699	6,167	1,841	4,521	1,949	7,795	964
9	363	4,638	6,077	1,814	4,513	1,945	7,781	963
10	370	4,581	5,991	1,788	4,506	1,942	7,769	961
11	377	4,522	5,904	1,762	4,500	1,940	7,759	960
12	384	4,466	5,820	1,737	4,493	1,937	7,747	959
13	391	4,422	5,752	1,717	4,491	1,936	7,743	958
14	398	4,370	5,675	1,694	4,487	1,934	7,736	957
15	405	4,326	5,668	1,674	4,486	1,933	7,734	957
16	412	4,280	5,539	1,653	4,485	1,933	7,773	957
400-POUND SOW [2]								
0	400	4,950	6,509	1,943	4,709	2,030	8,119	1,005
1	404	4,788	6,275	1,873	4,653	2,005	8,022	993
2	408	4,660	6,089	1,818	4,610	1,987	7,948	984
3	413	4,539	5,913	1,765	4,571	1,970	7,881	975
4	417	4,432	5,758	1,719	4,540	1,957	7,828	969
5	421	4,326	5,603	1,673	4,506	1,942	7,769	961
6	425	4,223	5,453	1,628	4,475	1,929	7,716	955
7	429	4,126	5,312	1,586	4,446	1,917	7,666	949
8	434	4,034	5,177	1,545	4,420	1,905	7,621	943
9	438	3,948	5,052	1,508	4,397	1,895	7,581	938
10	442	3,867	4,934	1,473	4,375	1,886	7,543	933
11	446	3,779	4,805	1,434	4,350	1,875	7,500	928
12	450	3,699	4,687	1,399	4,329	1,866	7,464	924
13	455	3,628	4,584	1,368	4,312	1,858	7,434	920
14	459	3,585	4,520	1,349	4,307	1,856	7,426	919
15	463	3,630	4,581	1,367	4,339	1,870	7,481	926
16	468	3,675	4,643	1,386	4,371	1,884	7,536	933

[1] Critical temperature at 0 week=36° F.; at 16 weeks = 46°.
[2] Critical temperature at 0 week = 41° F.; at 16 weeks = 50°.

TABLE 6.—*Daily food requirements, heat production, and gaseous exchange of a lactating 400-pound sow, fed to maintain body weight* [1]

Week of lactation	Milk produced daily	Total net energy required	Metabolizable energy required	Dry matter required	Total heat produced	Water vaporized		Carbon dioxide produced
						Under ordinary conditions	At 103° F. and above	
	Pounds	*Calories*	*Calories*	*Grams*	*Calories*	*Grams*	*Grams*	*Liters*
0	0.0	3,150	3,937	1,172	3,937	1,697	6,788	840
First	6.57	7,447	9,309	2,779	5,012	2,160	8,641	1,069
Second	7.86	8,290	10,363	3,093	5,223	2,251	9,005	1,114
Third	8.29	8,572	10,715	3,199	5,293	2,281	9,126	1,129
Fourth	8.00	8,382	10,477	3,127	5,245	2,261	9,043	1,119
Fifth	7.43	8,009	10,011	2,988	5,152	2,221	8,883	1,099
Sixth	6.57	7,447	9,309	2,779	5,012	2,160	8,641	1,069
Seventh	5.86	6,982	8,728	2,605	4,896	2,110	8,441	1,045
Eighth	5.14	6,512	8,140	2,430	4,778	2,059	8,238	1,019

[1] Critical temperature at 0 week=51° F.; at 1 week=37°; at 3 weeks=34°; at 8 weeks=41°.

Wöhlbier (*35*) also estimates much higher energy requirements for a lactating sow than those given in table 6. By interpolating in his table, a 400-pound sow would require during the first 4 weeks of lactation 4.8, 5.1, 5.0, and 6.6 kg starch equivalent, or, taking 1 feed unit to equal 0.7 kg starch equivalent (*12*), 6.8, 7.3, 7.1, and 9.4 feed units. However, these computations are based upon much larger milk yields of 11.9, 15.4, 15.0, and 18.0 pounds daily in the first 4 weeks of lactation. Wöhlbier claims in an earlier article (referred to in (*35*)) that ordinary methods of computing the milk yield of a sow by weighing the litter before and after suckling at regular intervals during a control day may greatly underestimate the milk that the litter would get when given free access to the udder, because the teats of the sow are quickly filled with milk and are also quickly emptied by the suckling pig, in as short a time as 25 to 35 seconds.

If Wöhlbier's contentions are correct, the calculations should be revised in accordance with his larger milk yields. Such a revision will be found in table 7 covering the first 4 weeks of lactation.

TABLE 7.—*Revision of table 6 to conform to Wöhlbier's larger estimates of milk yield*

Week of lactation	Milk produced daily	Total net energy required	Metabolizable energy required	Dry matter required daily	Total heat produced	Water vaporized		Carbon dioxide produced	Critical temperature
						Under ordinary conditions	At 103° F. and above		
	Pounds	*Calories*	*Calories*	*Grams*	*Calories*	*Grams*	*Grams*	*Liters*	*°F.*
First	11.9	10,932	13,665	4,079	5,883	2,536	10,143	1,255	26
Second	15.4	13,222	16,528	4,934	6,456	2,783	11,131	1,377	18
Third	15.0	12,960	16,200	4,836	6,390	2,754	11,017	1,363	18
Fourth	18.0	14,922	18,653	5,568	6,881	2,966	11,864	1,468	13

This revision raises the estimates of dry matter requirements to the estimate of Morrison and even above for the peak of lactation. Expressed on the basis of 12 percent of moisture to make them comparable with Scandinavian feed units, the requirements for successive weeks are 4.6, 5.6, 5.5, and 6.3 kg. Even these are considerably below Wöhlbier's values. This discrepancy must be due to a much lower assumed utilization of metabolizable energy by Wöhlbier.

USE OF BASIC DATA FOR THE DESIGN OF HOG-HOUSE VENTILATION SYSTEM

HOG HOUSE TEMPERATURES

The average rectal temperature of hogs is 102.5 F. with a range from 101.6° to 103.6°. Physiologists (*11*, *29*) tell us that a hog is not a completely thermoregulated animal and at temperatures above 79° physical regulation of body temperature is no longer sufficient. Every hog raiser knows the danger of high summer temperatures and the need of shade. The critical temperature of the hog is shown to be approximately 68° under basal conditions and varies with the plane of nutrition, being lower for large hogs on normal feed (table 3). Capstick and Wood (*8*) found that for each degree Fahrenheit drop below the critical temperature there was an increase in the rate of

metabolism of a little less than 3 percent. At temperatures of 18° pigs have been observed to shiver, and the increased heat production calls for more feed. Thus physiological reactions at the lower temperature limits, coupled with practical observations, suggest the desirability of temperatures not lower than 50° to 55° for a farrowing house. Somewhat lower temperatures are permissible for fattening hogs because of their higher plane of nutrition, but house temperatures approaching freezing should be avoided for all classes. There is need for greatly improving the ordinary farm hog house. Such houses are commonly found with little or no ventilation and are poorly lighted. Where a considerable number of hogs are to be provided for, it is believed that a good hog house, well ventilated and lighted, will show a return, for the capital invested, at least equal to that for any other structure on the farm.

Iowa studies (*16*) reveal that, with the poorer type of hog house, each drop of 10° F. below normal weather temperatures at farrowing time was associated with losses of about 5 percent of the pigs, and that careful housing reduced ordinary losses materially.

It is said that when small pigs are kept too warm they are less thrifty. On the other hand, chills together with dampness are often fatal to small pigs.

DATA FOR THE DESIGN OF HOG HOUSES

A knowledge of the rates of heat production and carbon dioxide and water vapor output of various farm animals as affected by weight, age, feed, and environmental conditions, is essential to the agricultural engineer, as a basis for the scientific design of structures for housing the animals, since the animal heat is utilized not only for maintenance of desirable stable temperatures but also for the removal, by ventilation, of the products of respiration, particularly water vapor. Removal of the water vapor at a rate that will maintain desirable conditions of atmospheric humidity is a distinct aid to maintenance of health and to sanitation.

The data presented in previous pages of this paper furnish an approximate basis for scientific design, though the estimates of water vaporized under ordinary conditions, equivalent to 25 percent of the total heat output, may be in excess of actual vaporization at temperature ranges between 32° and 50° F. These data have been, in part, converted to British thermal units and are shown graphically in figures 1 and 2 in order to bring out the relations of the several factors to each other and to make them more immediately useful to engineers and architects in the design of buildings adapted to maintain adequate ventilation and proper temperatures and thus aid in improving sanitary conditions and decreasing annual losses of early pigs in the community type of hog house.

The data for figure 1 were obtained from table 3 and those for figure 2 from tables 3, 5, and 6.[3] It is recognized that there is no standard relation between age and weight and rate of daily gain, since these vary with feeding practices. However, the plotting of these factors in figure 1 helps one to visualize their approximate relationship under good American feeding practices. Figure 1, *A*, is plotted to an irregular scale of ordinates, so that the normal average

[3] The heat production curve for the 400-pound nursing sow represents minimal estimates. The larger estimates given in table 7 may be more in conformance with practice.

live weight of a pig of any age that has gained according to the rates of gain indicated is shown approximately by reading horizontally across to figure 1, *B*. For convenience the carbon dioxide production

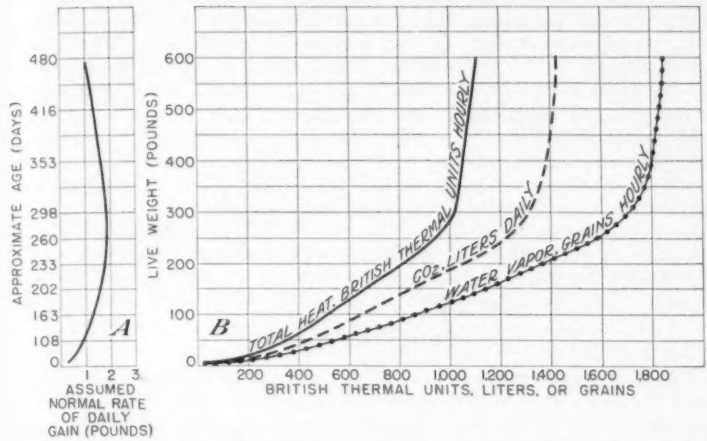

FIGURE 1.—*A*, Approximate normal growth of swine; *B*, total hourly heat and water-vapor production and daily carbon dioxide production for growing and fattening hogs.

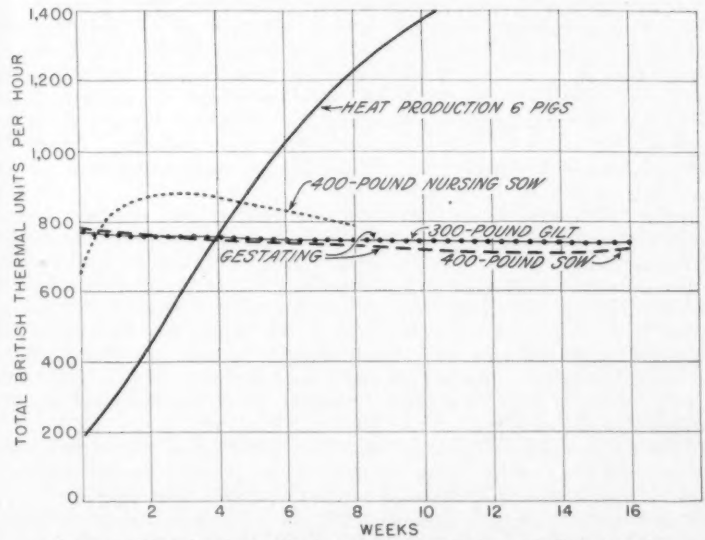

FIGURE 2.—Hourly heat production of gestating and nursing sows and a litter of six pigs.

data in figure 1, *B* are retained in the original form for the present and transposed in an example later. It is noted (fig. 1, *A*) that the rate of gain assumed in these calculations begins to decrease at approximately 250 pounds live weight and that the rate of heat

production as well as of carbon dioxide and water vapor (fig. 1, *B*) increases less rapidly at weights above 300 pounds.

Figure 2 compares the heat production of a 400-pound sow, nursing six pigs, with those of a 300- and a 400-pound sow during the period of gestation. Assuming the rate of gain shown in table 3, the additional heat produced by growing pigs is also shown. It is readily noted that the metabolism of the sow is at a low point after farrowing, but by the end of the first week is above that of the gestating sow, although lower than that of the fattening hog.

It is also noted that the difference in heat production between the 300- and 400-pound sows during gestation is small. The heat production of a male is higher than that of a female. For all practical purposes in making allowance for a boar we may increase the estimate of heat production over that of a sow of the same weight by 10 percent, although in some cases (p. 817) higher allowances may be advisable. These data permit a design for a particular condition and show the possible range of efficient operation of the ventilation system.

VENTILATION REQUIREMENTS[4]

The ventilation requirement of a given animal house may be based upon the heat and moisture production. It would appear that the amount of ventilation that would make efficient use of the heat produced and maintain a dry house would be the most desirable. In order to test out the usefulness of the data presented they are compared briefly with a test, the details of which are recorded elsewhere (*18*). The important features of this test are as follows: It was possible in a good hog house in Minnesota housing 1 boar, 54 fat hogs, and 50 shoats, to maintain fairly uniform temperature and adequate ventilation. Under an outside temperature of 24° F. ranging from 17° to 32°, an average inside temperature of 44° was obtained, ranging from 40° to 50°. The relative humidity ranged from 73 to 84 with an average of 80 percent. The average ventilation maintained was 1,649 cubic feet of air per minute.

In the test house were 26,775 pounds total weight of hogs, which would represent 89 hogs of 300 pounds average weight. However, since rate of heat production varies in young and older hogs, different heat values are required in estimating the heat production of different classes of hogs. By using the values given in figure 1, a total of 81,702 B. t. u. per hour is obtained in the above test house, or an equivalent of 80 head of 300-pound hogs. The average heat production for a 300-pound hog is thus estimated at 1,025 B. t. u. per hour (fig. 1), which is somewhat higher (660 B. t. u.) than that given by Armsby and Kriss (*2*).

If the air in a ventilated hog house is at 50° F. and 80-percent relative humidity, a pound of dry air passing out is accompanied by 43.1 grains of moisture. A pound of dry air entering from outside has a moisture content of 22.5 grains, when the outside air is at 32° and 85-percent relative humidity. Each pound of dry air circulated through the house by ventilation, therefore removes from the house the difference, or $43.1-22.5=20.6$ grains of moisture. Figure 1 shows that a 300-pound hog respires 1,719 grains hourly. To re-

[4] Acknowledgment is made of the assistance and the constructive criticism offered by S. J. Dennis, associate refrigeration engineer, with respect to analysis of heat balance.

move this moisture as fast as it is respired requires an air circulation rate of 1,719÷20.6, or 83.5 pounds of air (dry air) per hour. The specific volumes of the incoming and outgoing air under the given conditions are 12.46 and 12.97 cubic feet per pound of dry air respectively, and the total volume of the incoming air will be 83.5×12.46 or 1,040 cubic feet per hour, and that of the outgoing air 83.5×12.97 or 1,083 cubic feet per hour. This is the ventilation rate required per 300-pound hog to remove the respired moisture as fast as the hog exhales it, assuming that the rate at which water vapor is given off by the hogs is the same at 50° as at 68°. If the rate at which water vapor is given off is less at lower temperatures the ventilation requirements and attendant heat loss will be correspondingly reduced. At present no data for amount of water transpired at low temperatures are available.

The total heat content, under conditions already stated, of the incoming air is 11.17 and that of the outgoing air 18.57 B. t. u. per pound of dry air. Each pound of dry air circulated, therefore, removes a quantity of heat equal to the difference between 18.57 and 11.17=7.40 B. t. u., and the total heat carried out by ventilation at the rate calculated above will be 83.5×7.40=618 B. t. u. per hour, per 300-pound hog. The heat production of a 300-pound hog is 1,025 B. t. u. per hour (fig. 1, *B*). Heat lost by ventilation sufficient to remove the moisture respired by the hog is 618÷1,025×100, or 60.3 percent of the heat produced by the hog. Under the conditions stated above the balance is sufficient to maintain the temperature of an ordinarily well constructed house at the 50° level.

The air volumes required in ventilation sufficient to remove the moisture produced by the hogs, and the heat lost by such ventilation, may be similarly calculated for any given set of temperature and humidity conditions. Data on moisture, heat content, and volume are readily determined by reference to a psychrometric chart or table such as is found in several handbooks on ventilation or air conditioning.

Calculations for various outside and inside temperature conditions will show that when temperatures are low, both inside and outside, ventilation at the rate calculated to remove moisture as fast as given off (assuming a constant rate of production) would involve such large heat losses that all the heat produced by the hog would be carried off by ventilation, leaving no heat available to maintain the temperature of the building. This means that, for practical operation, it will be necessary in cold weather to reduce the amount of ventilation below the calculated requirement, in order to maintain satisfactory temperatures in the hog house. It is obvious that the better the construction and insulation of the house, the less its ventilation will have to be reduced.

Figure 2 shows that the period of low heat production is at farrowing time and during the first week thereafter. Hence for early pigs for zone 1 (*19*) and for the northern part of zone 2 it is often profitable to provide artificial heat during this period. Lanterns, radiant heaters, or furnaces may be used. The cost of installation may range from 85 cents to $6,000 or more for a complete system. However, it is seldom necessary to provide heat for more than a few pens and that but for a few days following farrowing. Scattered dates of farrowing for sev-

eral sows of each herd will decrease the number of heated pens needed. Thus, some form of localized heat or a pig brooder such as the one recently introduced by J. R. Tavernetti and E. N. Hughes, of the California Agricultural Experiment Station, may be had at a small annual cost even if rate of fuel cost is high for a short period. These electric brooders may be made portable and permit of transfer from one pen to the other at the critical period. They provide warmth and protection while the pigs are resting, and the surrounding cooler air stimulates appetite and vigor while the pigs are active. Thus in choosing a form of heat or the temperatures to be maintained in a farrowing house, the farmer must determine the number of sows likely to farrow at one time, the expected outside temperatures, and the number of days that heat will be needed.

SIZE OF FLUE

The total size of the flue in the above hog-house test was 12.2 square feet, and it carried out an average of 1,649 cubic feet of air per minute, with an average velocity of about 135 feet per minute. This volume equals 1,237 cubic feet per hour and the flue size equals 22 square inches per 300-pound hog equivalent. Using the volume of 1,083 cubic feet of air required per hour per head to satisfy ventilation conditions, and the above average flue velocity of 135 feet per minute obtained under actual working conditions, and substituting these values in the usual formula, $Q = V.\ A.$, it is found that 20 square inches of flue area per 300-pound hog would have been sufficient.

The data shown and methods outlined in this paper should enable the engineer to proceed with increased confidence in the design of structures to meet requirements imposed by various conditions such as capacity of building, class of hogs, and climate.

SUMMARY

An analytical study has been made of the energy requirements of swine for each of the various animal functions, as revealed by published information, and of an integration of these requirements for application to pigs of any particular age, weight, or condition. In this study the various animal functions have been differentiated for separate analysis, the ultimate values established then being applied to any particular animal as needed.

The general procedure has been to estimate the energy requirements of swine by factoring out and assessing as accurately as possible all items contributing to energy expenditure or storage. These factors have then been integrated for pigs of particular weights and conditions. Estimates of the net availability of the metabolizable energy of feed permit the conversion of net energy into metabolizable energy values. From the latter dry-matter requirements have been estimated for definite, more or less typical rations.

Summation of energy expenditures, via basal metabolism, muscular activity and heat increment of feed, leads to an estimate of heat production. From this, estimates of the probable output of carbon dioxide and of the usual and maximal output of water vapor have been made. Complete estimates of this kind have been made for growing and fattening gilts and burrows, both according to American and English feeding

practice, a pregnant gilt and a pregnant sow, and a lactating sow. Tentative estimates of critical temperatures have been made in each case.

The data given and the methods outlined will, it is believed, enable engineers to proceed with increased confidence in the design of structures to meet the requirements imposed by various conditions such as capacity of building, class of hogs, and climate. The findings are transposed into the form of basic data suitable to aid in the design of hog-house ventilation systems and illustrations of thier application are given.

LITERATURE CITED

(1) ARMSBY, HENRY PRENTISS.
1917. THE NUTRITION OF FARM ANIMALS. 743 pp., illus. New York.

(2) ——— and KRISS, MAX.
1921. SOME FUNDAMENTALS OF STABLE VENTILATION. Jour. Agr. Research 21: 343–368.

(3) BONSMA, F. N., and OOSTHUIZEN, P. M.
1935. MILK PRODUCTION IN LARGE BLACK SOWS AND ITS IMPORTANCE IN RELATION TO THE PRODUCTION OF WEANERS. So. African Jour. Sci. 32: 360–378, illus.

(4) BREIREM, KNUT.
1933. NÆRINGSHOVET FOR AVLSPURKER [FEED REQUIREMENTS OF SOWS]. Nord. Jordbruksforsk. 15: 421–439. [Abstract in Nutrition Abs. and Revs. 4: 200. 1934.]

(5) ———
1934. THREE YEARS' CONTROL TEST OF FEED REQUIREMENTS FOR BREEDING SOWS. Meld. Norges Landbr. Høiskole 14: 1–87, illus. [Abstract in Expt. Sta. Rec. 72: 676. 1935.]

(6) ———
1935. UNDERSØGELSER OVER VÆKSTEN HOS SWIN. II. ENERGIOMSÆTNINGEN HOS SVIN. Beret. Forøsgslab. K. Vet. og Landbohojskoles [Denmark] 162de, 277 pp., illus.

(7) BRODY, SAMUEL, HALL, W. C., RAGSDALE, A. C., and TROWBRIDGE, E. A.
1932. GROWTH AND DEVELOPMENT WITH SPECIAL REFERENCE TO DOMESTIC ANIMALS. XVIII. RELATION BETWEEN BASAL METABOLISM, RESTING METABOLISM, HEAT-INCREMENTS OF FEEDING AND BODY WEIGHTS IN GROWING FARM MAMMALS. Mo. Agr. Expt. Sta. Research Bull. 166: 45–65, illus.

(8) CAPSTICK, J. W., and WOOD, T. B.
1922. THE EFFECT OF CHANGE OF TEMPERATURE ON THE BASAL METABOLISM OF SWINE. Jour. Agr. Sci. [England] 12: [257]–268, illus.

(9) CARROLL, W. E., BULL, SLEETER, RICE, J. B., LAIBLE, R. J., and SMITH, R. A.
1929. SWINE TYPE STUDIES. I. TYPE IN SWINE AS RELATED TO RATE AND ECONOMY OF GAINS. Ill. Agr. Expt. Sta. Bull. 321, pp. 343–392, illus.

(10) DEIGHTON, THOMAS.
1929. A STUDY OF THE METABOLISM OF TWO BREEDS OF PIG. (WITH SOME REMARKS ON A THIRD.) Jour. Agr. Sci. [England] 19: [140]–184, illus.

(11) ———
1935. A STUDY OF THE FASTING MATABOLISM OF VARIOUS BREEDS OF PIG. II. BODY TEMPERATURE MEASUREMENTS. Jour. Agr. Sci. [England] 25: [180]–191, illus.

(12) EDIN, H., and HELLEDAY, T.
1935. UNDERSOKNINGAR ANGÅENDE BACONSVINETS NETTOENERGIBEHOV (UNDERHÅLLS- OCH PRODUKTIONSFODER) OCH TILLVÄXT MELLAN 15 OCH 90 KG. LEV. VIKT SAMT EN DEL DÄRPA INVERKANDE FAKTORER. Meddel. Centralanst. Försöksv. Jordbruksområdet [Sweden] 449, Husdjursavdelningen Nr. 87, 92 pp., illus. [In Swedish. English summary, pp. 88–91.]

(13) FINGERLING, GUSTAV:
1932. UNTERSUCHUNGEN ÜBER DEN STOFF- UND ENERGIEUMSATZ WACHSENDER SCHWEINE. Landw. Vers. Sta. 113: [273]–318.

(14) Hansson, N., and Bengtsson, S.
1930. der allgemeine nahrungsbedarf der mastschweine beleuchtet durch praktische fütterungsversuche. Tierernährung 1: 578–607.
(15) Hogan, A. G., Weaver, L. A. Edinger, A. T., and Trowbridge, E. A.
1925. the relation of feed consumed to protein and energy retention. Mo. Agr. Expt. Sta. Research Bull. 73, 42 pp., illus.
(16) Hopkins, John A. Jr.
1928. an economic study of the hog enterprise in humboldt county. Iowa Agr. Expt. Sta. Bull. 255, pp. [69]–110, illus.
(17) Hughes, E. H., and Hart, Hugh G.
1935. production and composition of sow's milk. Jour. Nutrition 9: 311–322.
(18) Kelley, M. A. R.
1922. test of a hog house ventilation system. Agr. Engin. 3: 164–167, illus.
(19) ———
1930. ventilation of farm barns. U. S. Dept. Agr. Tech. Bull. 187, 73 pp., illus.
(20) Krüger, Heinz Willy.
1930. schlachtbeobachtungen und ausschlachtungsversuche an schweinem. I. ein beitrag zur erforschung der keimdrüsenhormone in ihrer bedeutung für die schweinemast. Tierernähr. u. Tierzucht. (Wiss. Arch. f. Landw., Abt. B) 3: [75]–138, illus.
(21) Mitchell H. H., Carroll, W. E., Hamilton, T. S., and Hunt, G. E.
1931. food requirments of pregnancy in swine. Ill. Agr. Expt. Sta. Bull. 375, pp. 467–504, illus.
(22) ——— and Haines, W. T.
1927. the critical temperature of the chicken. Jour. Agr. Research 34: 549–557, illus.
(23) ——— and Hamilton, T. S.
1929. swine type studies. III. the energy and protein requirements of growing swine and the utilization of feed energy in growth. Ill. Agr. Expt. Sta. Bull. 323, pp. 403–600, illus.
(24) ——— and Kelley, M. A. R.
1933. estimated data on the energy, gaseous, and water metabolism of poultry for use in planning the ventilation of poultry houses. Jour. Agr. Research 47: 735–748.
(25) Morrison, F. B.
1936. feeds and feeding; a handbook for the student and stockman. Ed. 20, unabridged, 1050 pp., illus. Ithaca, N. Y.
(26) Popoff, J. S.
1928. die nettoenergie der gerste bei der mästung der wachsenden schweine. Ztschr. Tierzucht. u. Züchtungsbiol. 12: [289]–299, illus.
(27) Rapport, David, Weiss, Robert, and Csonka, Frank A.
1924. animal calorimetry. twenty-eighth paper. the respiratory metabolism of a young pig as influenced by food and benzoic acid. Jour. Biol. Chem. 60: 583–601.
(28) Robison, W. L.
1919. effect of age of pigs on the rate and economy of gains. Ohio Agr. Expt. Sta. Bull. 335, pp. 543–575, illus.
(29) Tangl, Franz.
1912. die minimale erhaltungsarbeit des schweines. (stoff- und energieumsatz im hunger). Biochem. Ztschr. 44: [252]–278, illus.
(30) Wellmann, O.
1921. über den stoff- und energieumsatz junger ferkel auf grund von fütterungsversuchen, verbunden mit der zerlegung ganzer ferkelkörper. Biochem. Ztschr. 117: [119]–139.
(31) Whetham, Elizabeth O.
1935. tables showing the carcass weight, carcass percentage, and age in relation to the live weight of pigs. Pig Breeders' Ann. (1934–35) 14: 188–203.

(32) WIERZUCHOWSKI, M., and LING, S. M.
1925. ANIMAL CALORIMETRY. TWENTY-NINTH PAPER. ON FAT PRODUCTION IN A YOUNG HOG. Jour. Biol. Chem. 64: 697–707, illus.
(33) WILKENS, CHRISTEL.
1930. DIE KÖRPERENTWICKLUNG DES HANNOVERSCHEN VEREDELTEN LANDSCHWEINES BIS ZUM ABSCHLUSS DES WACHSTUMS. Tierernähr. u. Tierzucht. (Wiss. Arch. f. Landw., Abt. B) 3: [20]–74.
(34) WINKLER, GERHARD.
1932. SCHLACHTBEOBACHTUNGEN UND AUSSCHLACHTUNGSVERSUCHE AN SCHWEINEN. III. ZWEITER BEITRAG ZUR ERFORSCHUNG DER KEIMDRÜSENHORMONE IN IHRER BEDEUTUNG FÜR DIE SCHWEINEMAST SOWIE EIN THYMUSDRÜSENHORMONVERSUCH. Arch. f. Tierernähr. u. Tierzucht. 7: [346]–394, illus.
(35) WÖHLBIER, WERNER.
1930. DER NÄHRSTOFFBEDARF SÄUGENDER SAUEN. Tierernähr. u. Tierzucht. (Wiss. Arch. f. Landw., Abt. B) 3: [627]–630.
(36) WOOD, T. B.
1926. STUDIES OF THE NUTRITION OF YOUNG ANIMALS. I. ENERGY EXCHANGES IN THE GROWING PIG. Jour. Agr. Sci. [England] 16: [425]–442, illus.

TOXICITY OF SELENIUM FED TO SWINE IN THE FORM OF SODIUM SELENITE [1]

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INTRODUCTION

Considerable loss of livestock in the north-central Great Plains has been attributed to a disease, known locally as alkali disease, which was considered to be due to the deposits of alkali in the soil. The symptoms manifested by affected animals included loss of hair from the mane and tail of horses, the switch of cattle, and hair from the body of swine. Marked alteration in the growth of the horn of the hoof of all these species was also a prominent symptom, resulting in some cases in a sloughing of the hoof.

In a previous paper (*9*) [3] it was shown that hogs fed at the Bureau of Animal Industry Experiment Station, Bethesda, Md.,[4] on two lots of corn grown in an area where the so-called alkali disease existed developed typical clinical symptoms of this disease. It was found that the two lots of corn contained selenium in the proportion of 10 and 5 parts per million, respectively.

Since this and other information (*1*, *2*, *4*, *5*, *6*, *7*) indicated that selenium in the feed was a responsible factor in the production of the so-called alkali disease, experiments were undertaken to study the effects, on swine, of selenium when given in various quantities mixed with the daily ration.

As selenium in the organic form was not available, these tests were conducted with selenium in the form of an inorganic salt, sodium selenite.

EXPERIMENTAL PROCEDURE

In order to test the effect of feeding selenium in the daily ration, 10 pigs (9 Duroc-Jerseys and 1 Berkshire) about 4 months old were placed in a concrete barn entirely separate from any other pigs at the Bureau's Experiment Station at Bethesda, Md., on April 2, 1934. Each animal had an individual pen about 10 feet long and 5 feet wide, well bedded with straw. Wooden troughs were used for feed and water. Water was kept before the pigs all the time and was from the regular station supply. Each animal was weighed as soon as it was placed on experiment and on several other occasions during the first week to determine the gains made on the normal feed. Weights were taken at weekly intervals thereafter.

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[2] The writers are indebted to H. C. Dudley, formerly of the Bureau of Chemistry and Soils, for the chemical analysis of body parts and fluids for selenium, and to H. G. Byers, of that Bureau, for assistance in preparing the dosage of selenium. Acknowledgment is also made to G. T. Creech, of the Bureau of Animal Industry, for the histopathological examination of the various organs, and to M. S. Shahan, W. B. Shook, C. D. Stein, and C. N. Dale, of that Bureau, for the post-mortem examination of these animals.

[3] Reference is made by number (italic) to Literature Cited, p. 842.

[4] This station, now known as the Animal Disease Station, was moved to Beltsville, Md., in 1935.

The grain feed, which was the mixture fed regularly to hogs at the Experiment Station, consisted of bran 2 parts, corn feed-meal 1 part, alfalfa meal ½ part, and gluten meal 1 part. It was given at the rate of about one-half pound per 10 pounds of body weight a day, and the quantity increased as fast as the animals would consume it. That the feed was adequate is demonstrated by the weekly gains in weight made by the two control pigs (Nos. 4326 and 4327), as shown in table 1. At the end of the first week, selenium in varying quantities was added to the feed of eight pigs (principals), which were divided into pairs. The selenium was given in the form of a tenth molar solution of sodium selenite (17.3 g of dry salt per liter of distilled water). The solution was measured by pipette to give the desired number of parts per million of elementary selenium and was thoroughly mixed with the grain feed, which had been previously weighed and moistened with a measured volume of water.

TABLE 1.—*Weekly quantities of grain feed and selenium consumed and changes in weights of pigs used in experiment*

Pig No.	Week No.	Dry feed		Selenium eaten	Change in weight of pig [1]
		Given	Eaten		
		Ounces	*Ounces*	*Milligrams*	*Pounds*
4326 (control)	1	175	175.0	.....	+3.5
	2	189	189.0	.....	+3.5
	3	210	210.0	.....	+3.25
	4	238	238.0	.....	+2.25
	5	266	266.0	.....	+5.0
	6	294	294.0	.....	+5.25
	7	329	329.0	.....	+3.5
	8	350	350.0	.....	+5.25
	9	378	378.0	.....	+5.0
4327 (control)	1	154	154.0	.....	+2.5
	2	168	168.0	.....	+3.5
	3	189	189.0	.....	+6.0
	4	210	210.0	.....	−1.5
	5	238	238.0	.....	+5.5
	6	252	252.0	.....	+2.0
	7	280	280.0	.....	+5.25
	8	308	308.0	.....	+4.75
	9	336	336.0	.....	+6.0
4328	1	154	24.8	244.8	−4.5
	2	154	6.2	60.0	−.5
	3	154	8.1	79.2	−3.25
	4	154	28.0	288.0	−2.0
	5	132	[2] 28.8	[2] 288.0	−.75
	6	154	9.4	91.2	−2.0
	[3] 7	88	8.8	86.4	.....
4329	1	168	23.5	261.6	−4.25
	[4] 2	.....	.....	.....	.....
4330	1	182	[2] 43.3	[2] 225.6	−2.25
	2	182	[2] 17.9	[2] 93.6	−2.25
	3	182	15.3	79.2	−2.75
	4	182	14.3	74.4	−3.25
	5	156	4.2	21.8	−1
	[5] 6	.....	.....	.....	.....
4331	1	126	40.0	228.0	−1.75
	2	126	10.2	58.2	−2.25
	3	126	20.6	117.7	−2.75
	4	126	8.0	45.7	−2.75
	5	108	4.5	25.9	−1
	[6] 6	.....	.....	.....	.....

Pig No.	Week No.	Dry feed		Selenium eaten	Change in weight of pig [1]
		Given	Eaten		
		Ounces	*Ounces*	*Milligrams*	*Pounds*
4332	1	238	238.0	324.0	−1.5
	2	204	64.4	84.0	−.5
	3	238	59.5	77.1	−2.5
	4	238	36.6	48.6	−3.0
	5	204	9.5	12.4	−2.5
	6	238	35.0	45.4	−3.0
	7	272	36.0	47.0	−6.0
	8	204	8.8	11.6	−2.5
	9	238	11.3	14.8	−4.0
4333	1	175	125.4	171.4	+.5
	2	175	86.4	118.2	+.5
	3	175	56.5	77.2	−1.75
	4	175	20.0	27.2	−4.0
	5	150	7.4	10.1	−.75
	6	175	13.2	18.0	−2.25
	7	200	17.6	24.0	−1.5
	8	150	1.0	1.5	−.5
	9	200	4.9	6.7	−2.0
	10	150	10.7	14.6	−1.5
	11	175	19.0	26.0	−2.0
	12, 13, 14.	550	62.3	85.1	−3.0
4334	1	168	168.0	117.6	+2.5
	2	175	175.0	123.2	+3.0
	3	196	[2] 62.0	[2] 43.0	−3.75
	4	196	35.8	24.8	−4.25
	5	168	31.8	22.0	−.5
	6	196	16.2	11.3	−.5
	7	224	32.6	22.5	−1.5
	8	168	22.6	15.7	−1.0
	9	224	26.7	18.5	−2.0
	10	168	11.5	8.2	−2.5
	11	196	20.7	14.4	−3.0
4336	1	182	182.0	128.8	−2.5
	2	189	189.0	134.4	+4.0
	3	210	210.0	145.6	+3.75
	4	245	245.0	173.6	+1.25
	5	245	192.6	131.5	0
	6	266	120.0	79.5	−.5
	[7] 7	152	69.7	46.0	.....

[1] + indicates gain in weight; −, loss.
[2] Quantity estimated, as feed was spilled.
[3] Pig died at the end of 5 days of this week.
[4] Pig died at the end of 3 days of this week, during which time animal would not eat.
[5] Pig died at the end of 4 days of this week, during which time animal would not eat.
[6] Pig died at the end of 2 days of this week, during which time animal would not eat.
[7] Pig died at end of 4 days of this week.

TABLE 2.—*Summary of results of sodium selenite feeding experiment*

Pig No.	Initial weight	Period from beginning of experiment to death of pig	Final weight	Change in weight [1]	Total dry feed eaten	M/10 solution of sodium selenite per ounce of feed	Total selenium eaten	Selenium in grain feed	Results
	Pounds	*Days*	*Pounds*	*Pounds*	*Pounds*	*Centimeters*	*Grams*	*P. p. m.*	
4326 (control)	38.5	[2]	[3] 75.0	+36.5	151.8	0	0	0	
4327 (control)	30.5	[2]	[3] 64.0	+33.5	133.4	0	0	0	
4328	33.5	46	20.5	−13.0	7.1	1.4	1.14	392	41 days after experiment began, pig was very weak, had diarrhea. Post-mortem examination showed gastroenteritis; feet and hair normal.
4329	36.5	10	32.25	−4.25	1.5	1.4	.26	392	No symptoms of selenium poisoning; apparently died of acute poisoning.
4330	42.0	38	30.5	−11.5	6.0	.7	.49	196	Marked weakness after 14 days; on twenty-eighth day loss of hair from back. Post-mortem examination showed complete loss of hair on back and some above feet; swelling of coronary band, especially on front feet.
4331	26.0	36	15.5	−10.5	5.2	.7	.48	196	Marked weakness after 27 days. Post-mortem examination showed gastroenteritis; hair and feet normal.
4332	49.5	66	24.0	−25.5	31.2	.17	.66	49	Loss of hair and break in coronary band, after 57 days, on all 4 feet. Post-mortem examination showed loss of hair, break in coronary band, ⅛ inch, on all 4 feet; edema around joints, no erosions; bone marrow of femur red and gelatinous.
4333	38.5	99	20.0	−18.5	26.5	.17	.58	49	Loss of hair on back after 37 days. Post-mortem examination showed loss of hair on back; no foot lesions; yellow gelatinous exudate around and in joints; no erosions.
4334	36.0	79	22.5	−13.5	37.7	.087	.42	24.5	Loss of hair after 27 days; foot lesions appeared later. On post-mortem examination all 4 feet showed separation of skin from hoof, about 1 inch wide; loss of hair on back and around feet; edema around joints but no erosions; marrow of long bones red and gelatinous.
4336	41.0	46	51.5	+10.5	75.5	.087	.84	24.5	No loss of hair or foot lesions. Post-mortem examination showed gastroenteritis.

[1] +indicates gain in weight; −, loss.
[2] Animal lived throughout experiment.
[3] At the end of 63 days.

The first pair of principals received grain containing 392 parts of selenium per million, the second pair 196 p. p. m., the third pair 49 p. p. m., and the fourth pair 24.5 p. p. m. (table 2). The quantity of feed given to the controls was increased each week, whereas the feed for the pigs receiving the grain to which selenium had been added was increased only when the daily ration had been cleaned up regularly in the preceding week. The moist feed was kept before the pigs for 3 to 4 hours, when any feed remaining in the box was weighed and discarded. To determine how much selenium had been consumed by each pig, the weight of the feed left in the box was deducted from that given and the selenium content calculated on the basis of the feed eaten. It was not possible to calculate definitely the quantity of feed left in some cases because of the box having been overturned.

EXPERIMENTAL RESULTS

Feeding data and changes in weights of the pigs, by weekly periods, are shown in table 1. Summaries of the results of the tests are shown in tables 2 and 3.

TABLE 3.—*Summary of the results of analyses,*[1] *for selenium content, of principal body parts and fluids of pigs 4328, 4329, 4332, and 4336 (principals) and control pig 4327*

[Results given in terms of per million of selenium parts, based on weight of samples of body parts and fluids taken on post mortem]

Body part or fluid	Selenium content[2] of indicated body part or fluid of—				
	Pig 4328	Pig 4329	Pig 4332	Pig 4336	Pig 4327
	P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*
Bile		3	T	6.0	
Blood (clots from heart and larger arteries)	0.5	5.0	2.0	0.2	0
Bone (left femur)	1.0		7.0	T	0
Bone marrow of left femur	T		2.0	0	0
Brain				0	
Hair	0			0	
Heart (muscular tissue only)	T	T	5.0	0	0
Hoof (horny portion only)	20.0		8.0	8.0	0
Hoof joint			.3		
Intestines (large) and contents	1.5	38.5	8.0	[3] T	0
Intestines (small) and contents	1.0	3.5	2.0	1.0	0
Kidney	13.0	4.0	25.0	3.0	0
Leg joint (hock)			4		0
Leg muscle	0		2.0	0	0
Liver	3.0	3.0	10.0	4.0	0
Lungs	T	1.5	2.0		0
Skin (free of hair and dirt)	1.0		T	.8	
Spleen	0	T	T	1.5	0
Stomach (washed free of contents)		0		.5	[4] 0
Testicles			0		
Urine (taken from bladder)	0.1		3.0		0

[1] The methods of analysis used by H. C. Dudley in making these determinations are described in publications by Dudley and Byers (*5*) and Robinson and co-workers (*8*).

[2] T = Trace.

[3] Contained large number of roundworms.

[4] Stomach with contents examined.

CONTROL ANIMALS

Pigs 4326 and 4327, the two control animals, remained normal for the duration of the experiment. Pig 4327 was killed to compare the weights of the organs with those of one of the principals, No. 4332, and also to determine whether or not selenium was present in the tissues. No selenium was found in pig 4327, as shown in table 3.

PRINCIPAL ANIMALS

PIG 4328

Pig 4328 ate relatively little feed after the second day of the experiment and became progressively weaker. It was unable to stand after 41 days and death occurred in 46 days. No clinical evidence of selenium poisoning, such as loss of hair along the back or around the feet, or foot lesions, was observed at any time. On post-mortem examination the only lesions noted were an acute gastroenteritis.

In the histological examination of the liver, very little capillary engorgement was found, but there was considerable deposition of bile pigment, and in some areas a noticeable increase in the interstitial tissue as well as a limited leucocytic and round-cell infiltration. A very large percentage of the liver cells showed various stages of fatty degeneration and marked vacuolation. In some lobules the degenerative changes were more marked around the central veins, whereas in others the changes were not confined to any particular part. Whole columns of cells in some lobules showed practically complete degeneration and disintegration of the cytoplasm, only the cell wall and occasionally the nucleus remaining.

In the kidney, thrombi were observed in a number of the larger veins and there was also some capillary engorgement, as well as evidence of edema, and many of the glomeruli were greatly shrunk or atrophied. The kidney epithelium showed indications of more or less degeneration throughout, but the more marked changes were confined to certain groups of tubules, in many of which complete desquamation of the epithelium had occurred.

In the skin the principal changes noted were in the hair and hair follicles. These consisted of well-marked atrophy, and in a number of follicles, also degeneration which appeared to involve the hair sheath. There were more or less disintegration of the cellular elements and formation of small clumps of fragments, which stained deeply with eosin, suggestive of hyaline change. Heavy deposits of green pigment were noted in a number of the hair papillae.

PIG 4329

Pig 4329 stopped eating 7 days after the experiment began and was in a moribund condition 10 days later, when it was killed. No clinical evidence of selenium poisoning was noted at any time.

Post-mortem examination showed that the peritoneal cavity contained about 50 cc of straw-colored fluid and the pleural cavity a similar quantity. No other changes were observed. No histological examination was made.

PIG 4330

Pig 4330 ate feed very sparingly, showed marked weakness 14 days after the beginning of the experiment, and began to lose hair along the back 14 days after weakness appeared. Denudation was complete 7 days after the hair began to fall, and the pig succumbed 38 days after the beginning of the experiment.

Post-mortem examination showed that the hair had entirely disappeared along the back from the neck to the tail, for a width of about 3 inches, and there was a marked loss of the white hair around the feet. A distinct swelling of the coronary band, similar to the earlier

foot lesions of so-called alkali disease, was present in the front feet and dew claws, and to a smaller extent in the hind feet (fig. 1). The internal organs appeared normal, with the exception of the liver, in which the lobules were slightly paler than normal and were quite prominent.

On histological examination of the liver, it was found that the changes varied in different lobules, from a slight cloudiness of the cytoplasm to complete degeneration of the cells. In some lobules practically all the cells showed extreme cloudy swelling, and in a few lobules engorgement with blood was found in the degenerated centers. Cell vacuolation was very slight and only a small quantity of pigment was noted. There was practically no increase in the interstitial tissue.

FIGURE 1.—Swelling of the coronary band of the feet of pig 4330. Note particularly swelling of front feet, as indicated by arrows.

In the kidney, little evidence of circulatory disturbance was found. The entire kidney epithelium appeared to be more or less involved in the degenerative changes, which consisted of extensive cloudiness and in certain of the tubules complete degeneration of the cells. In some areas noticeable vacuolation of the degenerated cells was observed. Atrophic changes were noted in many of the glomeruli, and a number of tubules contained hyalin casts.

In the spleen, small degenerated areas were observed in which the cells were undergoing fatty changes.

PIG 4331

Pig 4331 ate little after the second day of the experiment, and 26 days later had difficulty in controlling the hind legs. No loss of hair or changes in the feet were noted. The animal died 36 days after the experiment began.

Post-mortem examination showed severe gastroenteritis, but no macroscopic changes were observed in the other organs.

On histological examination of the liver the sections showed capillary engorgement throughout with some evidence of edema. Although there was more or less cloudiness of the liver cells with definite degeneration of individual cells or small groups of cells, the degenerative changes were not so well marked nor so extensive as those observed in the livers of other animals. There were limited leucocytic and round-cell infiltration and also some increase in the interlobular connective tissue.

In the kidney, the epithelium showed a cloudy swelling in many of the tubules, loss of nuclei, and limited fatty changes in the cell protoplasm. There was some desquamation of the tubules, and a number of the tubules contained casts. Some indication of edema was found, and a considerable number of glomeruli showed more or less atrophy. Little pigment was present in this case.

PIG 4332

In pig 4332 there was marked loss of hair, about 2 inches wide, from the poll to the tail, 57 days after the experiment began, and also a distinct break in the coronary band on all four feet. Later the separation of the coronary band from the wall of the hoof became much more pronounced, permitting considerable mobility of the hoof. The animal died 66 days after the experiment began.

Post-mortem examination showed the carcass to be in very poor condition. The hoofs on all four feet showed distinct breaks, about one-eighth inch wide, around the coronary band. The cervical lymph glands were congested, and the muscles in the throat region appeared to be edematous. The heart was flabby, but the lungs revealed no macroscopic lesions. A mild gastritis was present. The liver seemed smaller than usual, the lobules were prominent, and some light-colored areas, the size of a pea, were present. Nothing unusual was noted in the spleen, kidneys, and bladder. The tissues around the joints appeared edematous, but no erosions were found upon examination. The bone marrow of the femur was red and gelatinous, similar to the condition seen in animals affected with so-called alkali disease.

Post-mortem changes in the liver rendered the histological examination somewhat unsatisfactory. Many of the liver cells were undergoing fatty changes, with vacuolation of the cytoplasm, but complete cell destruction was apparently limited to individual cells or small groups of cells. The outstanding change was the extensive proliferation of the interstitial tissue, the capsule of the organ being very much thickened and the interlobular connective tissue greatly increased. Bile pigment was found in many of the cells.

On histological examination of the kidney, capillary congestion and degenerative changes which were more advanced in certain groups of tubules were found in this organ. There was desquamation of the tubular epithelium and in a few tubules practically complete destruction of the epithelium. In some areas fatty changes with cell vacuolation were noticeable. Small pigment deposits were noted.

Examination of the spleen showed little deviation in this organ from the normal.

Weights of the organs of selenium-fed pig 4332 are compared with the weights of the organs of control pig 4327 in table 4.

TABLE 4.—*Comparative weights of organs of selenium-fed pig 4332 and control pig 4327*

Organ	Weight of organs of—		Organ	Weight of organs of—	
	Pig 4332	Pig 4327		Pig 4332	Pig 4327
	Grams	*Grams*		*Grams*	*Grams*
Heart	100	115	Liver	180	715
Kidneys	90	135	Spleen	20	80
Lungs	340	420	Testicles	50	220

At the beginning of the experiment, as shown by table 2, pig 4327 weighed 30.5 pounds and pig 4332 weighed 49.5 pounds, whereas at the conclusion of the experiment pig 4327 weighed 64 pounds and pig 4332 weighed only 24 pounds. Pig 4327 therefore had gained 33.5 pounds, whereas pig 4332 had lost 25.5 pounds. In pig 4332 the lower weights of the heart, lungs, kidneys, and spleen (table 4) are probably due to the general loss in weight. In the case of the liver and testicles, however, the differences in the weights of the organs seem too great to be explained on this basis.

PIG 4333

Pig 4333 (fig. 2, *C*) began to lose hair along the back 37 days after the beginning of the experiment. No involvement of the feet was noted at any time. The animal died 99 days after being placed on experiment.

Post-mortem examination showed that the skin was denuded of hair along the spinal column to the tail and there was icterus of the skin and sclera. The heart was flabby and the fat was gelatinous. Some inflammation was present at the pyloric end of the stomach. The liver showed hard, hobnaillike lesions. In the kidneys, the pelvis and calyxes were filled with a gelatinous exudate. The spleen and intestines appeared normal. The joints were enlarged owing to a yellow, gelatinous exudate in the surrounding tissue, but no erosions were found on the articular surfaces. Histological examination was not made.

PIG 4334

The hair along the back of pig 4334 was loose 27 days after the experiment began, and 18 days later an area of several inches on either side of the spinal column, from the head to the tail, was practically denuded (fig. 2, *B*). In about 2 months a break appeared in the coronary band of the feet, becoming progressively wider until the separation attained a width of about 1 inch in the front feet (fig. 3). The animal lived 79 days.

On post-mortem examination all four feet and dew claws showed separation of the hoof to about 1 inch, leaving a raw area. Apparently the tissue from which the horn develops had been impaired since no new hoof was developing. There was loss of hair around the feet and down the back. The carcass was in poor condition and no

FIGURE 2.—Pigs 4333 (*C*), 4334 (*B*)—two of the principals used in the experiment—and 4326 (*A*), one of the controls. Pig 4333 shows loss of hair along the backbone, typical of selenium poisoning. Pig 4334 shows a small loss of hair, principally over the shoulders. Photograph was taken toward the end of the experiment.

FIGURE 3.—Front feet of pig 4334, which show a characteristic lesion of selenium poisoning in the marked separation of the hoof from the skin at the coronary band.

fat was present, a gelatinous substance having replaced this tissue. The heart was flabby and the fat had a gelatinous appearance. There was gastritis but no enteritis. The spleen appeared normal, but the liver was very hard and small and in one lobe the lobules stood out prominently. The bladder had a yellowish exudate on the mucous surface, which was thickened and showed several small hemorrhages. No erosions were found in the joints, but a gelatinous material was present around some of them. The marrow of the long bones was reddish and gelatinous but not to so marked a degree as in some of the other pigs.

Histological examination of the liver showed a well-marked degeneration of the liver cells, which appeared to be more extensive in some portions of the organ than in others. A definite central necrosis was present in a number of lobules, and these necrotic areas had been invaded by polymorphonuclear leucocytes. Considerable bile pigment, mostly intracellular, had been deposited in the organ, and there was rather extensive proliferation of the interstitial tissue. No other tissue was taken from this animal.

Pig 4336

Pig 4336 never showed any clinical symptoms of selenium poisoning other than a slight loss of appetite 10 days before death, which occurred rather suddenly. This animal lived 46 days.

On post-mortem examination the only lesion observed in the animal was gastroenteritis.

On histological examination of the liver, most of the interlobular veins showed engorgement and a limited number of the lobules showed capillary congestion. Many of the lobules contained areas, varying in size, of degenerated cells in many of which vacuoles were noted. Central necrosis appeared in a few lobules. A small quantity of bile pigment was observed, and there was well-marked proliferation of the interstitial tissue, both interlobular and intralobular.

In the kidney there was more or less blood engorgement throughout the organ. Although much of the tubular epithelium showed cloudy swelling and some desquamation in addition, the more advanced degenerative changes were limited to individual tubules or small groups of tubules. These changes paralleled somewhat those noted in the kidney of pig 4331. There was considerable deposition of pigment also.

In the skin some atrophic changes appeared in certain of the hair follicles.

With regard to the deposition of selenium in the tissues, table 3 shows that the results of the chemical analysis, for selenium content, of the body parts or fluids of pigs 4328 and 4336 are very similar with the exception of the kidney and hoof. Both of these animals lived 46 days, but the quantity of selenium consumed by pig 4328 was 1.14 g as compared with only 0.84 g consumed by pig 4336 during the same period. This difference, then, might account for the larger quantity of selenium found in the kidney and hoof of pig 4328.

DISCUSSION

The clinical symptoms shown by swine affected by the so-called alkali disease in certain areas in the north-central Great Plains States are manifested by a loss of hair and a marked alteration in the growth of the horn of the hoof, which apparently begins as an inflammation of the coronary band and results in an interruption of the normal growth of horn. This is followed by a distinct break in the horn with a marked separation between the new and the old horn. In addition to these symptoms, diarrhea, stiffness, posterior paralysis, marked loss of condition, and death have been observed occasionally following the feeding of alkali grain to swine. Post-mortem examination of several field cases showed a gelatinous condition around the joints, and the marrow of the long bones was reddish, soft, and gelatinous.

The symptoms and lesions produced in the experimental pigs by the ingestion of sodium selenite are similar to those seen in affected swine in the localities where this condition prevails and to those produced by feeding toxic corn outside the area, as reported in a previous paper (*9*).

Of the eight pigs fed sodium selenite, four showed a definite loss of hair most marked along the back; two of the four had distinct breaks in the feet between the skin and hoof at the coronary band; and one had marked swelling of the coronary band. These pigs received the following number of parts of selenium per million parts of grain: 196 parts by pig 4330; 49 parts by pig 4332; 49 parts by pig 4333; 24.5 parts by pig 4334. The remaining four animals showed more or less evidence of enteritis, either clinically or at post mortem. One had diarrhea and several of the others showed marked weakness. All the animals, with the exception of pig 4336, lost weight and all died within 10 to 99 days after the feeding of sodium selenite was begun. Their loss in weight was due, at least in part, to the small quantities of feed consumed. Early in the experiment these animals showed a marked aversion to selenium-treated grain, a characteristic which has been noted in pigs consuming grain in which selenium occurs under natural conditions.

There appears to be considerable variation in the tolerance of the individual pigs to the action of selenium. This is evidenced both by the apparently acute poisoning of pig 4329, which lived only 10 days after consuming 0.26 g of selenium, and by the appearance of clinical symptoms of the disease in some animals (pigs 4330, 4332, 4333, and 4334), which received a larger total quantity of selenium and lived much longer than pig 4329. This difference is further illustrated in the case of three other animals (pigs 4328, 4331, and 4336) which died without showing typical clinical symptoms, although the quantity of selenium consumed and the period of survival were more or less comparable to those of the four pigs which developed lesions. In pig 4332, which survived 66 days, it appears that there was continued deposition of selenium in the various body parts or fluids, in spite of the greatly reduced quantities of the element ingested in the latter part of the feeding period (table 1). Inasmuch as pig 4329 appears to have died of acute poisoning, the differences in the selenium content of the blood and intestinal tract may be due to the large quantity of the salt taken in during the short period of survival (table 1).

SUMMARY

Experiments were made to determine the relationship of selenium to the so-called alkali disease and the effects of selenium in feed given to pigs at different levels over a period of time. Eight pigs about 4 months old were divided into four groups and were fed an adequate grain ration to which selenium in the form of sodium selenite was added in the proportions of 392, 196, 49, and 24.5 parts per million, respectively. Four, or 50 percent, of these animals showed clinical symptoms similar to those seen in natural cases of so-called alkali disease, manifested by a loss of hair and interference with the growth of the horn of the hoof. All the animals died in from 10 to 99 days and showed post-mortem lesions similar to those seen in the so-called alkali disease. Two other pigs, fed the same grain to which no sodium selenite had been added, made normal gains in weight during the feeding period and remained healthy at all times.

The pigs fed the sodium selenite ate very sparingly, leaving a large part of their daily ration untouched, and their loss in weight may be attributed, at least in part, to this factor. The two control pigs kept under identical conditions and receiving the same feed except for the addition of sodium selenite, made gains in weight and remained healthy at all times. After the first few feedings there was evidence of a marked aversion to the feed to which selenium was added. After refusing this feed, animals readily ate normal feed on several occasions when it was offered to them. Aversion to grain in which selenium occurs under natural conditions has been reported from the field.

LITERATURE CITED

(1) Beath, O. A., Eppson, H. E., and Gilbert, C. S.
1935. selenium and other toxic minerals in soils and vegetation. Wyo. Agr. Expt. Sta. Bull. 206, 56 pp., illus.

(2) Byers, Horace G.
1935. selenium occurrence in certain soils in the united states with a discussion of related topics. U. S. Dept. Agr. Tech. Bull. 482, 48 pp., illus.

(3) Dudley, H. C., and Byers, H. G.
1935. determination of selenium; quantitative determination on animal matter and clinical test in urine. Indus. and Engin. Chem., Analyt. Ed. 7: 3–4.

(4) Franke, Kurt W., and Potter, Van R.
1935. a new toxicant occurring naturally in certain samples of plant foodstuffs. ix. toxic effects of orally ingested selenium. Jour. Nutrition 10: 213–221, illus.

(5) ——— Rice, T. D., Johnson, A. G., and Schoening, H. W.
1934. report of a preliminary field survey of the so-called "alkali disease" of livestock. U. S. Dept. Agr. Cir. 320, 10 pp., illus.

(6) Knight, Henry G.
1935. the selenium problem. Jour. Assoc. Off. Agr. Chem. 18: 103–108.

(7) Robinson, W. O.
1933. determination of selenium in wheat and soils. Jour. Assoc. Off. Agr. Chem. 16: 423–424.

(8) ——— Dudley, H. C., Williams, K. T., and Byers, H. G.
1934. determination of selenium and arsenic by distillation in pyrites, shales, soils, and agricultural products. Indus. and Engin. Chem., Analyt. Ed. 6: 274–276, illus.

(9) Schoening, H. W.
1936. production of so-called "alkali disease" in hogs by feeding corn grown in affected area. North Amer. Vet. 17.

THE MEASUREMENT AND INHERITANCE OF SCAB RESISTANCE IN SELFED AND HYBRID PROGENIES OF POTATOES[1]

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INTRODUCTION

In any attempt to breed potatoes (*Solanum tuberosum* L.) for scab resistance one is immediately faced with the problem of accurately measuring the observed differences. The relative usefulness of different methods of measurement can be ascertained by comparing the consistency with which they present evidence of significant inherited differences in scab resistance. In this paper is presented a study of the technique of measuring differences in scab reaction between seedling progenies, together with the relation of selfed and hybrid progenies in respect to these differences.

MATERIALS AND METHODS

The tests for scab resistance were made on a plot of peat soil at the Coon Creek experimental farm near Anoka, Minn. The soil of a greater portion of the plot is rather heavily infested with *Actinomyces scabies* (Thax.) Güss., and had grown scabby crops of potatoes for 4 successive years. In 1936, when it was necessary to increase the size of the plot, some soil was included on which potatoes had not been grown in recent years and which was somewhat less heavily infested.

The seedling progenies tested included 33 selfed lines and 27 crosses. The number of seedlings in the different families ranged from 25 to 350. Each family was planted in approximately equal numbers in three randomized blocks. Many of the parents had been tested as clones, and differences had been observed which appeared to be significant. The progenies studied were started from seed in September and the seedlings were grown to maturity in the coldframe and greenhouse in the fall of 1935. Small tubers ranging from ¼ to 1 inch in diameter were harvested. These were planted in the field test plots in the spring of 1936. The small size of the tubers planted, together with unusually hot and dry weather during midsummer, resulted in late setting and a light crop of relatively small tubers. In general, the scab infection on the seedling families was less than that on the common varieties and older selections in the test plot. This relatively light infection tended to decrease the range of variability in the

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amount of scab, thus increasing the importance of accuracy in measurement.

When the crop was harvested the tubers from each hill were placed in a separate paper bag and taken to the laboratory for a more careful examination of scab infection. The tubers were washed before scab readings were made. Each individual tuber was given a rating on the basis of resistance to scab infection according to the following scale:

0=No scab.
1=Very small lesions—very resistant.
2=Small lesions—moderately resistant.
3=Medium-sized lesions—showing some evidence of resistance.
4=Large lesions—no evidence of resistance.

After all of the tubers of a hill had been classified according to the above scale, a scab rating for the hill was obtained by multiplying the number of tubers in each class by the number of the class and dividing the product by the total number of tubers in the hill. Thus each hill received a numerical rating falling somewhere between 0 and 4, inclusive, corresponding to its observed susceptibility to scab; the larger the figure, the greater the susceptibility. The scab rating for a seedling family was obtained by averaging the ratings of the individual hills of the family.

Before the notes were taken, tubers representing each class in the scale were selected and photographed at natural size (fig. 1). All readings were made by one person who had the photographs before him at all times. The seedling families were labeled by row number only and their identity was unknown to the observer, so that there was no opportunity for bias.

It will be noted that in the photographic scale the samples of the more susceptible types of lesion always involve a larger surface area of infection. This correlation was illustrated because it agrees with previous observations and because it was expected and desired that the ratings be influenced to some extent by the amount of surface area infected. The scab rating, however, is based primarily on resistance as manifested in the type of lesion and secondarily on the amount of surface area infected. In other words, a tuber with a single large susceptible-type lesion would be rated as susceptible, but a tuber with a relatively high percentage of its surface area affected with scab composed of small, shallow, resistant-type lesions would be rated as resistant.

Clark, Raleigh, and Stevenson[2] used data based on the amount of surface area of the tubers affected with scab in arriving at a numerical "scab index" in a test of varietal resistance to scab. The type of lesion is given as supplementary data by these workers and is not used in computing the scab index. In the present method the results of both criteria of measurement are combined in a single numerical rating, thereby facilitating the use of all data in statistical analyses. The end result of these two methods may not differ greatly, because there is obviously some agreement between resistance as indicated by the type of lesion and as indicated by the amount of surface area affected in a given test. In general, the more resistant the

[2] CLARK, C. F., RALEIGH, W. P., and STEVENSON, F. J. BREEDING FOR RESISTANCE TO COMMON SCAB IN THE POTATO. Amer. Potato Jour. 13: 256–259. 1936.

lesion type, the smaller is the area affected. However, striking exceptions are often observed. It is believed that a single, large, susceptible-type lesion on a tuber is more likely to indicate susceptibility than resistance. Using the surface-area method of arriving at a scab index, such a tuber would weight the results on the side of resistance and constitute a source of error that could be eliminated only by numerous replications and checks that are not possible in many types of test.

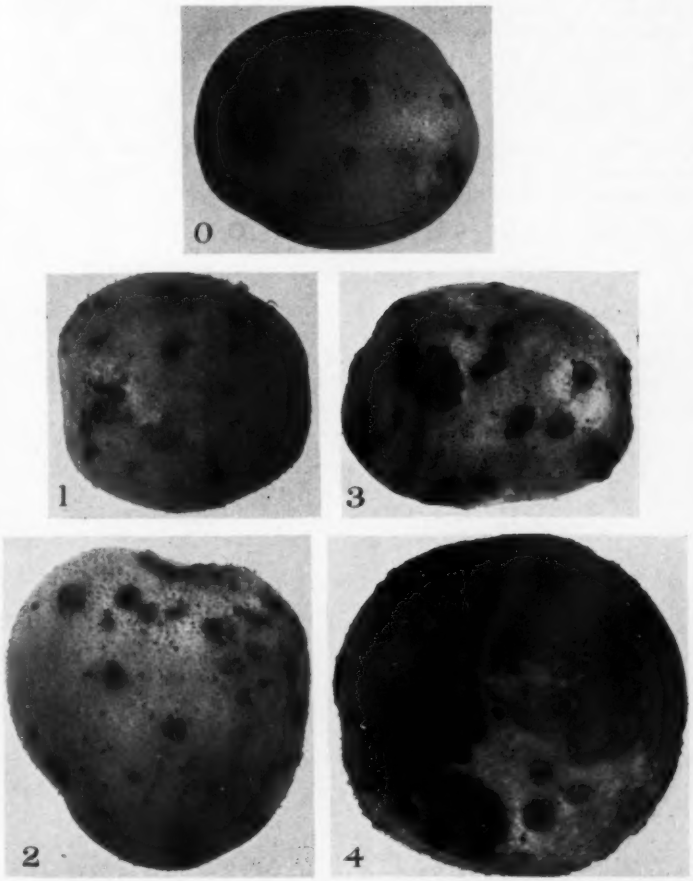

FIGURE 1.—Five tubers illustrating the scale used in rating the relative scab resistance of potatoes tested, those shown representing the minimum limits for each class: 0, No scab; 1, very small lesions—very resistant; 2, small lesions—moderately resistant; 3, medium-sized lesions—showing some evidence of resistance; 4, large lesions—no evidence of resistance. × 4/5.

Four different methods of classifying the material were used. The first method included the ratings on all tubers regardless of size. The second method included the ratings only on those tubers larger

than 1 inch in diameter. It was thought that many of the smaller tubers would have escaped infection and would constitute a source of error.

In the third method each hill was given a rating corresponding to the most susceptible-type lesion found on any tuber in the hill. The justification for this method is based on the theory that if one tuber in the hill is susceptible to a given degree all others in the hill are potentially susceptible to an equal degree but have escaped infection. If this method should prove reliable it would greatly simplify the task of testing for scab resistance.

The fourth method consisted in rapidly rating each hill into one of the five classes on the basis of the predominant type of scab lesion among all the tubers of the hill. An attempt was made to have this method somewhat comparable to what would be accomplished if the individual hills were rated in the field at harvest time.

EXPERIMENTAL RESULTS

METHOD OF MEASURING SCAB

The data obtained by these various methods of classification are presented in tables 1 and 2. In table 1 are given the data on the inbred families; the data on the crosses are given in table 2. The data are separated into two tables merely for convenience. The analysis of variance was applied to the data as a whole.

TABLE 1.—*Mean scab ratings of 33 inbred families as measured by the 4 different methods*

Family	All tubers	Large tubers	Highest scab	Predominant scab type
81-1	1.58	1.70	2.21	1.48
11-1-3-2	1.34	1.30	2.12	1.60
82-1	1.06	1.26	2.06	1.37
29-14	1.08	1.16	1.82	1.34
29-13	1.00	1.21	1.48	1.46
11-1-2-1	.78	1.01	1.57	1.00
13-1	.54	.96	1.40	1.24
11-8-1-9-1	.72	.93	1.48	1.22
3-2-4	.82	.92	1.61	1.32
34-1-1	.84	.90	1.59	1.13
12-2-4-1-7	.74	.82	1.56	1.29
9-1	.70	.88	1.40	1.14
29-13-5	.51	.81	1.50	1.12
40-2-2	.70	.80	1.42	1.14
10-4-2	.51	.78	1.34	1.03
1-4-2	.49	.78	1.56	1.20
82-8	.51	.76	1.33	1.00
82-6	.47	.68	1.30	1.04
11-1-2-1-1	.42	.64	1.31	1.08
82-10	.49	.64	1.43	1.10
82-11	.45	.58	1.21	1.14
82-4	.59	.68	1.37	1.06
82-2	.56	.67	1.70	1.26
11-8-1-9-3	.54	.63	1.32	1.08
11-8-1-9-4	.45	.59	1.36	1.10
11-1-2-2-4	.44	.56	1.26	1.02
5-10-1	.46	.52	1.33	1.07
14	.36	.52	1.15	1.03
1-1	.35	.50	1.14	1.00
1-4-1	.32	.48	1.22	1.00
21-2-2	.36	.48	1.48	1.00
15-1	.31	.42	1.06	1.00
11-1-25	.24	.36	1.00	1.00
S. E. of difference	.167	.190	.214	.241
Difference required for significance	.33	.38	.43	.48

Because of the loss of 1 replication of 16 families before notes were taken, there were 3 replications for only 44 of the families. The data were analyzed separately for two and three replications. The results of these analyses are given in table 3. When the variance for error for three replications is compared with that for two replications it is seen that the third replication added relatively little to the reliability of measurement. This is probably because the third replication was planted on soil that was less heavily infested with scab. In view of this fact, and because it was desired to use the data on certain families with only two replications, the data based on two replications only were used in further consideration of the results of the experiment.

TABLE 2.—*Mean scab ratings of 27 hybrid families as measured by the 4 different methods*

Cross No.	Parents	All tubers	Large tubers	Highest scab	Predominant scab type
123.35	Triumph × 4-25-7-1	1.54	1.67	2.54	1.80
121.35	Warba × 11-1-3-2	1.17	1.28	2.24	1.56
119.35	Warba × 12-2-4-1-7	1.00	1.16	1.78	1.32
31.35	11-1-3-2 × 40-4-2-5-1	.98	1.14	1.94	1.46
125.35	Triumph × 40-2-2-2-1	1.04	1.12	1.84	1.00
194.35	Early Ohio × 12-2-4-1-7	.80	.99	1.84	1.40
118.35	Warba × 5-10-1	.78	.94	1.60	1.24
111.35	Early Ohio × 5-10-1	.80	.91	1.61	1.22
112.35	Early Ohio × 41-1-1-7-6-1	.80	.89	1.56	1.26
27.35	11-1-2-1 × 39-3-1-1-5	.76	.88	1.66	1.27
124.35	Triumph × 5-10-1	.78	.87	1.66	1.23
107.35	82-10 × 12-2-4-1-7	.76	.84	1.59	1.22
148.35	Russet Rural × 5-10-1	.70	.84	1.57	1.34
164.35	Erstling × 40-2-2	.72	.84	1.72	1.10
32.35	11-1-2-2-4 × 21-2-2	.64	.74	1.53	1.00
172.35	116.30-1-31 × 4-25-7-1	.58	.74	1.64	1.29
165.35	Jubel × 5-10-1	.64	.73	1.26	1.14
39.35	11-8-1-9-4 × 21-2-2	.57	.72	1.62	1.26
104.35	82-4 × 12-2-4-1-7	.74	.72	1.71	1.25
1.35	4-9-3-1-1-1-1-1 × 5-10-1	.56	.70	1.62	1.08
84.35	74-1 × 21-2-2	.55	.64	1.54	1.16
173.35	116.30-1-31 × 5-10-1	.60	.64	1.10	1.26
113.35	Early Ohio × 4-9-3-1-1-1-1-1	.64	.64	1.66	1.20
9.35	4-25-6 × 5-10-1	.48	.55	1.49	1.20
5.35	4-9-3-1-1-1-1-1 × 82-10	.38	.52	1.40	1.06
167.35	Arnica × 5-14-8-1	.32	.38	1.06	1.00
166.35	Jubel × 5-14-8-1	.21	.30	1.03	1.18
	S. E. of difference	.167	.190	.214	.241
	Difference required for significance	.33	.38	.43	.48

TABLE 3.—*Summary of analyses of variance of data on scab resistance of 60 seedling families based on 4 different methods of measuring scab resistance, and on 2 or on 3 replications*

THREE REPLICATIONS

Variation due to—	Degrees of freedom	Variances			
		All tubers	Large tubers only	Mean highest scab rating	Predominant scab type
Families	43	[1] 0.215	[1] 0.216	[1] 0.283	[1] 0.065
Error	86	.029	.033	.043	.026

TWO REPLICATIONS

Families	59	[1] 0.108	[1] 0.165	[1] 0.194	0.057
Error	59	.028	.036	.058	.046

[1] The value of F exceeds the 1 percent point.

It is evident from table 3 that significant differences in scab susceptibility were revealed by all four methods of measurement, but the most effective method was that based on all tubers, closely followed by that based on large tubers only. The ratings based on the highest scab type gave significant differences between families, while the method of rating on the predominant scab type proved unsatisfactory.

A further test of the efficiency of the different methods of scab measurement was obtained by determining the degree of correlation between the mean scab ratings of related F_1 progenies. Theoretically, one would expect a positive correlation of the mean scab ratings of related progenies if the methods of measurement are reliable. Fourteen selections or varieties entered into one or more crosses. The coefficient of correlation for these related progenies was determined for each of the methods of recording the scab data. The coefficients of correlation were as follows:

All tubers	0.59	Highest scab type	0.34
Large tubers	.50	Predominant scab type	.08

The coefficient based on all tubers and on large tubers is highly significant, exceeding the 1-percent point. That based on the highest scab type exceeds the 5-percent point and is also significant, but that based on the predominant scab type is not significant. An analysis of variance of the mean scab ratings within and between these related groups as given in table 4 shows essentially the same relationship.

TABLE 4.—*Analysis of variance of scab ratings within and between groups of related F_1 families*

Variation—	Degrees of freedom	Variance			
		All tubers	Large tubers	Highest scab	Predominant scab type
Between groups	11	[1] 0.1636	[1] 0.1797	[1] 0.2222	0.0398
Within groups	25	.0309	.0357	.0459	.0221

[1] The value of *F* exceeds the 1 percent point.

The tubers in this experiment were small. That larger tubers would increase the accuracy of rating is suggested by a comparison of the selfed families with the hybrid families given in table 5. The 33 selfed lines yielded on an average about 50 percent less than the hybrids. Since the average number of tubers per plant did not differ greatly for the two groups, most of the difference in yield may be attributed to size of tubers. The average mean scab ratings for the two groups were the same only where none but the largest tubers in the hill were considered. For the other three methods of rating, the average scab ratings of the selfed lines are less than those of the hybrid families. Although these differences are not large, they suggest that the smaller tubers in the selfed lines, by escaping infection, may have caused a relatively lower mean scab rating of the selfed lines as compared with the hybrid families. If this were true, all other things being equal, one would expect the average mean scab

rating of the selfed lines to be considerably lower than that of the hybrid families. However, since many of the hybrid families were from crosses made for the specific purpose of introducing scab resistance, it is probable that this tended to equalize the average mean scab rating of the two groups. Additional evidence as to the reliability of the methods may be obtained from a consideration of tables 6, 7, 8, and 9. In tables 6, 7, and 8 the mean scab ratings of the progenies are listed in order of susceptibility on the basis of data on the large tubers. It will be noted in each table that the progenies do not retain the same relative position by each of the four methods of rating, but the general trend is the same. The rating of the progenies by the "predominant scab type" method is not in agreement with that obtained by the other methods. This method, as has been shown, is also the least reliable.

TABLE 5.—*Yield and scab ratings of the selfed lines and the hybrid families*

Item	Families	Mean number of tubers per plant	Mean yield per hill	Mean scab ratings			
				All tubers	Large tubers	Highest scab	Predominant scab type
	Number		*Grams*				
Selfed lines	33	4.10	86	0.65	0.797	1.45	1.15
Hybrid families	27	4.99	109	.72	.792	1.62	1.24
Difference required for significance				.060	.069	.078	.088

In table 9 those crosses that were included in the test and in which the scab resistance of the parents is known, are arranged in six groups on the basis of the susceptibility of the parents. The scab ratings of the progenies of these crosses are in striking agreement with the known scab resistance of the parents. It is difficult to believe that such close agreement could have been possible if the methods of measuring scab resistance had not been reasonably accurate.

HEREDITARY DIFFERENCES IN RESISTANCE BETWEEN PROGENIES

It can be shown that the observed differences in mean scab rating are hereditary by grouping together those hybrid families with a common parent and comparing the variance in mean scab rating within and between these groups of related families. Twelve groups, comprising 37 hybrid families, are available for comparison. In table 4 are given the variances obtained within and between groups by each of the four methods of classification. A significant difference was found between groups of related families by the "all tubers," "large tubers," and "highest scab" methods of rating. The results indicate that the mean scab ratings of the families within the groups were more similar than the ratings of the families in different groups. The uniformity obtained within groups can in part be ascribed to the influence of the common parent for each group of crosses and the significant variances obtained between groups is due to significant differences in breeding behavior for scab resistance between the common parents. The common parents and the average mean scab

rating for each of the 12 groups are given in table 6. It has been established that there remains a significant difference between these groups of related progenies after the removal of the variance due to the unrelated parents within each group (table 4). It is of interest to note that the Triumph, 11–1–3–2, and Warba show no breeding value for scab resistance. On the other hand, the variety Jubel and the selection 5–14–8–1 have a high breeding value, as indicated by the low mean scab ratings of their hybrid progeny. It would be unsafe to draw conclusions on the intermediate groups, although a further analysis of these parents indicates that some of them have considerable breeding value for scab resistance.

TABLE 6.—*The common-parent and the average-mean-scab rating for each of 12 groups of F_1 families*

Group No.	Common parent	F_1 families	Average scab rating of F_1 families			
			All tubers	Large tubers	Highest scab	Predominant scab type
		Number				
1	Triumph	3	1.12	1.22	2.01	1.34
2	11–1–3–2	2	1.08	1.21	2.09	1.56
3	Warba	3	.98	1.13	1.87	1.37
4	12–2–4–1–7	4	.82	.93	1.73	1.30
5	Early Ohio	4	.76	.86	1.67	1.27
6	5–10–1	8	.67	.77	1.49	1.21
7	40–2–2	2	.64	.78	1.67	1.18
8	21–2–2	2	.58	.69	1.54	1.08
9	82–10	2	.57	.68	1.50	1.14
10	4–9–3–1–1–1–1–1	2	.53	.62	1.56	1.11
11	Jubel	2	.42	.52	1.14	1.16
12	5–14–8–1	2	.26	.34	1.05	1.09
Difference required for significance[1]			.167	.190	.214	.241

[1] Between those groups containing more than 2 F_1 families a smaller difference would be required for significance.

TABLE 7.—*Mean scab rating of F_1 progenies of 8 parents, each crossed with line 5–10–1*

Cross No.	Parents	All tubers	Large tubers	Highest scab	Predominant scab type
118.35	Warba × 5–10–1	0.78	0.94	1.60	1.24
111.35	Ohio × 5–10–1	.80	.91	1.61	1.22
124.35	Triumph × 5–10–1	.76	.87	1.66	1.23
148.35	Russet Rural × 5–10–1	.70	.84	1.57	1.34
165.35	Jubel × 5–10–1	.64	.73	1.26	1.14
1.35	4–9–3–1–1–1–1–1 × 5–10–1	.56	.70	1.62	1.08
173.35	116.30–1–31 × 5–10–1	.60	.64	1.10	1.26
9.35	4–25–6 × 5–10–1	.48	.55	1.49	1.20
Difference required for significance		.33	.38	.43	(1)

[1] Not significant.

In the above study it has been shown that, when all the crosses in which a given parent entered are grouped, there are significant differences between the average mean scab rating of these groups. A comparison between the hybrid families within a group having a common parent is given in table 7. These eight hybrid families are taken from group 6, table 6, and consist of crosses between selection 5–10–1 and

eight other parents. It will be noted from table 7 that the largest differences between the mean scab ratings of the hybrid progenies approach twice the standard error. The five varietal parents gave hybrid families with mean scab ratings approaching the order of their behavior as clones in the varietal test plot. It would appear from these results that the method of crossing all individual selections to a common parent tends to bring out existing hereditary differences. However, in these tests it was a less satisfactory method of testing the breeding value of selections for scab resistance than the method of testing the selections in a group of crosses or of testing their selfed progenies.

TABLE 8.—*Mean scab rating of progenies of 10 parents when selfed and when crossed*

Parents	Selfed				Crossed			
	All tubers	Large tubers	Highest scab	Predominant scab type	All tubers	Large tubers	Highest scab	Predominant scab type
11–1–3–2	1.34	1.30	2.12	1.60	1.08	1.21	2.09	1.51
11–1–2–1	.78	1.01	1.57	1.00	.76	.88	1.66	[1] 1.23
12–2–4–1–7	.74	.82	1.56	1.29	.82	.93	1.73	1.30
40–2–2	.70	.80	1.42	1.14	.64	.78	1.67	1.18
82–4	.59	.68	1.37	1.04	.74	.72	1.71	[1] 1.25
82–10	.49	.64	1.43	1.10	.57	.68	1.50	1.14
11–8–1–9–4	.45	.59	1.36	1.10	.57	.72	1.62	[1] 1.26
11–1–2–2–4	.44	.56	1.26	1.02	.64	.74	1.53	[1] 1.00
5–10–1	.46	.52	1.33	1.07	.67	.77	1.49	1.21
21–2–2	.36	.48	1.48	1.00	.60	.69	1.54	1.08
Difference required for significance	.33	.38	.48	[2]	.33	.38	.43	[2]

[1] 1 cross only.
[2] Not significant.

The relation of the mean scab ratings of selfed lines with the average mean scab rating of all the crosses in which each line entered is given in table 8. This table shows the mean scab ratings of 10 selfed lines and the average mean scab rating for the hybrid families from each selection. Selfed lines 11–1–3–2 and 11–1–2–1 have a significantly higher mean scab rating than 5–10–1 and 21–2–2. Wider differences exist between the selfed lines than between their hybrid progenies. In the latter a significant difference is shown by 11–1–3–2, which, in both its selfed line and hybrid progenies, gave a high mean scab rating. In this comparison the selfed lines proved much more effective in bringing out significant differences between selections than their hybrid families.

In the studies so far presented the behavior of F_1 families has been compared with that of one parent of the cross. In table 9 the crosses are grouped according to the reaction of the parents to scab. The five groups are as follows: Susceptible × susceptible, susceptible × resistant, intermediate × intermediate, intermediate × resistant, and resistant × resistant. The parent varieties are classed as susceptible or resistant on the basis of 2 or more years' test. The parent selections were placed in the susceptible, intermediate, and resistant classes according to the mean scab rating of their selfed lines as given in table 8. The data show that the mean scab ratings of crosses

between susceptible parents are significantly higher than in the crosses of the susceptible × resistant group. This latter group has a higher scab rating than the group of crosses between intermediate and the intermediate × resistant group. The difference obtained between the latter two groups is insignificant. The crosses between the resistant parents gave a significantly lower average mean scab rating than the other four groups of crosses.

TABLE 9.—*Mean scab ratings of F_1 progenies of 14 crosses grouped according to the susceptibility of the parents*

Group	Type of cross [1]	Cross No.	Parents	Mean scab rating of F_1 progenies			
				All tubers	Large tubers	Highest rating	Predominant rating
1	S × S	121.35	Warba × 11-1-3-2	1.17	1.28	2.24	1.56
2	S × I	119.35	Warba × 12-2-4-1-7	1.00	1.16	1.78	1.32
		194.35	Ohio × 12-2-4-1-7	.80	.99	1.84	1.40
			Mean	.90	1.08	1.81	1.36
3	S × R	124.35	Triumph × 5-10-1	.78	.87	1.66	1.23
		118.35	Warba × 5-10-1	.78	.94	1.60	1.24
		111.35	Ohio × 5-10-1	.80	.91	1.61	1.22
			Mean	.79	.91	1.62	1.23
4	I × I	39.35	11-8-1-9-4 × 40-2-2	.57	.72	1.62	1.26
		104.35	12-2-4-1-7 × 82-4	.74	.72	1.71	1.25
		107.35	12-2-4-1-7 × 82-10	.76	.84	1.59	1.22
			Mean	.69	.76	1.64	1.24
5	I × R	32.35	11-1-2-3-4 × 21-2-2	.64	.74	1.53	1.00
		39.35	11-8-1-9-4 × 21-2-2	.57	.72	1.62	1.26
			Mean	.61	.73	1.58	1.13
6	R × R	167.35	Arnica × 5-14-8-1	.32	.38	1.08	1.00
		165.35	Jubel × 5-10-1	.64	.73	1.26	1.14
		166.35	Jubel × 5-14-8-1	.21	.30	1.03	1.18
			Mean	.39	.47	1.12	1.11
Difference between families required for significance [2]				.33	.38	.43	(3)

[1] S=susceptible; I=intermediate; R=resistant.
[2] A smaller difference would be required for significance between the group means.
[3] Not significant.

SUMMARY

The problem of measuring differences in scab resistance in potatoes was studied, with particular reference to difference between seedling families. A mean scab rating for each family was determined and expressed by the use of a numerical scale which gave a measure of resistance based on the type of lesion and also took into account the amount of surface area affected. By combining the results of both criteria of measurement in a single numerical rating, this scale facilitated the use of all the data in statistical analyses.

Four different methods of measurement were compared in a study of the reaction of 33 selfed lines and 27 hybrid families. In one method each tuber in the hill was classified according to the scale, and from these data an average rating for the hill was determined. In another method the average rating for the hill was based on the readings on

only those tubers larger than 1 inch in diameter. The average of the hill ratings was determined to obtain the mean scab rating of the family. Both of these methods gave very satisfactory results. Two simplified methods of measurement were based on the most susceptible type of lesion and the predominant type of lesion in a hill, respectively, but these were less satisfactory than the other two methods.

Significant differences in mean scab rating were obtained by all four methods of measurement. The most significant differences were obtained by the methods of "all tubers" and "large tubers," and the least significant by the predominant scab type method. In the further analyses of the breeding material the four methods maintained the same relative position as regards their effectiveness in measuring significant differences.

The hereditary nature of the differences in scab resistance found between the seedling families was shown by a greater variance between groups of crosses where each group had a common parent than within these groups. A direct comparison of these groups showed significant differences in reaction to scab and indicated the relative breeding value of the parents. Eight F_1 families having 5–10–1 as a common parent gave differences in mean scab rating which in some cases approached significance, indicating a difference between the unrelated parents in their ability to transmit scab resistance.

A significant difference between the mean scab rating of 10 selfed lines was associated with a similar but smaller difference between the averages of their hybrid families.

When the crosses were grouped according to the reaction of both parents it was found that crosses between susceptible parents gave a significantly higher mean scab rating than crosses of susceptible with resistant parents. The latter crosses had a significantly higher mean scab rating than crosses between intermediates and crosses of intermediate with resistant parents. The crosses between the resistant parents gave a significantly lower mean scab rating than any of the other four types of crosses.

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